Muon Accelerators:
An Integrated Path to Intensity and Energy Frontier Physics Capabilities

Mark Palmer

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Introduction and Context (I)

The US Muon Accelerator Program (MAP) is one of two DOE HEP Facilities R&D efforts

- The other is LARP
- Both are *directed* **accelerator R&D** efforts ⇨ next generation capabilities for deployment at existing HEP facilities

MAP's focus is on the R&D required to demonstrate feasibility of muon accelerators for HEP applications

- The Neutrino Factory (NF) on the Intensity Frontier
- The Muon Collider (MC) on the Energy Frontier

The two Muon Accelerator capabilities are strongly linked

- With key synergies that can be exploited to control technical risk and cost
- A unique breadth of physics that can be supported

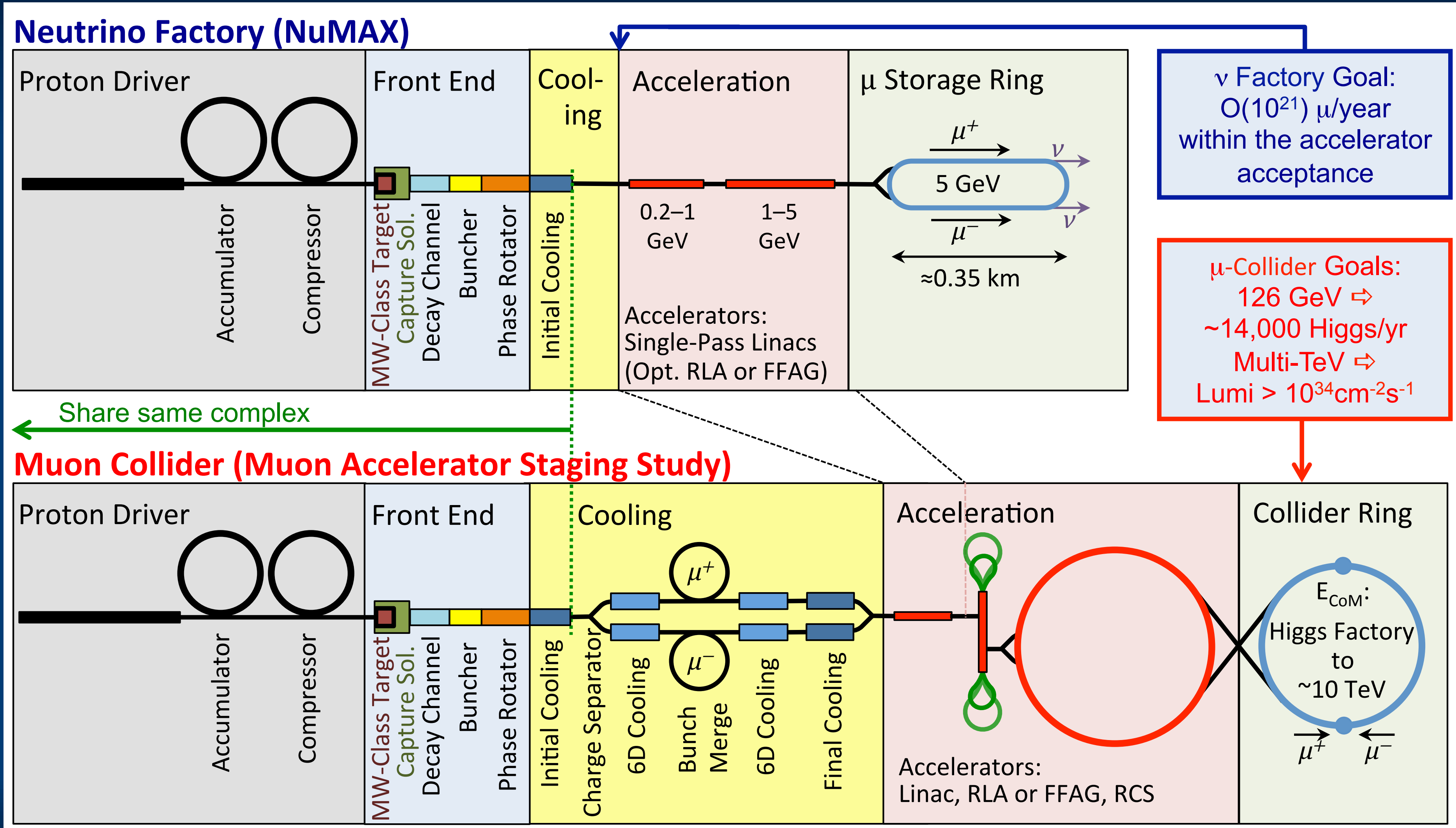
Introduction and Context (II)

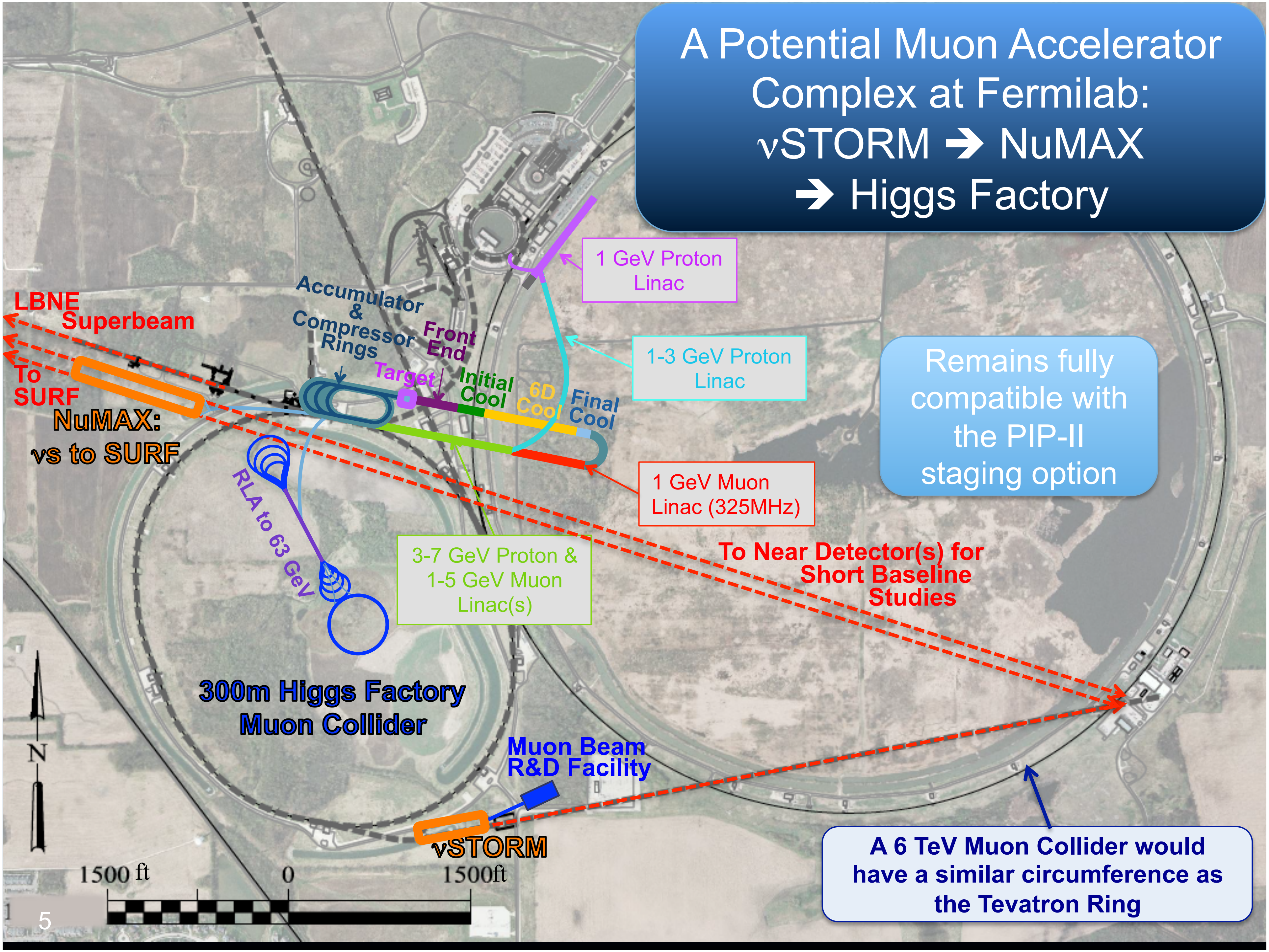
- The synergies and potential physics reach have been explored by the Muon Accelerator Staging Study (MASS) and documented in the Snowmass whitepaper:

  Enabling Intensity and Energy Frontier Science with a Muon Accelerator Facility in the US - http://arxiv.org/pdf/1308.0494

- Thus the committee has requested a joint presentation of the NF and MC concepts and capabilities

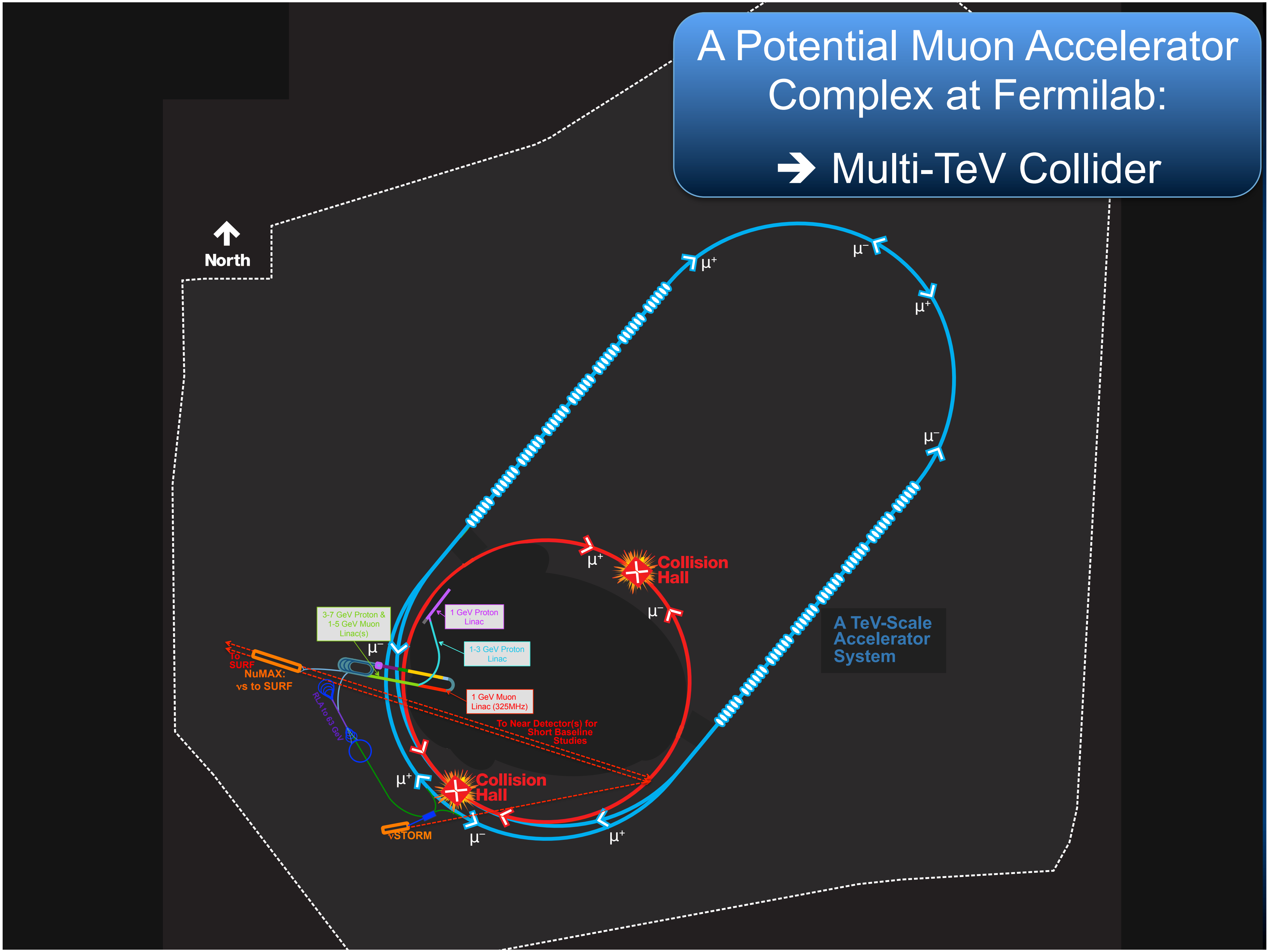
MC/NF Synergies




A Potential Muon Accelerator Complex at Fermilab: νSTORM ➔ NuMAX ➔ Higgs Factory
Remains fully compatible with the PIP-II staging option
1 GeV Proton Linac
1-3 GeV Proton Linac
1 GeV Muon Linac (325MHz)
3-7 GeV Proton & 1-5 GeV Muon Linac(s)
LBNE Superbeam
To SURF
NuMAX: νs to SURF
Accumulator & Compressor Rings
Front End
Target
Initial Cool
6D Cool
Final Cool
RLA to 63 GeV
To Near Detector(s) for Short Baseline Studies
300m Higgs Factory Muon Collider
Muon Beam R&D Facility
νSTORM
A 6 TeV Muon Collider would have a similar circumference as the Tevatron Ring
N
1500 ft
0
1500ft

A Potential Muon Accelerator Complex at Fermilab:

→ Multi-TeV Collider



Brief summary of the physics cases coupled with the explicit scope of the experiments

- Notional Timeline (construction start, data taking, specific anticipated results)
- Unique features and fit to overall picture

ITEM 1 FROM P5

Physics Case for the Neutrino Factory

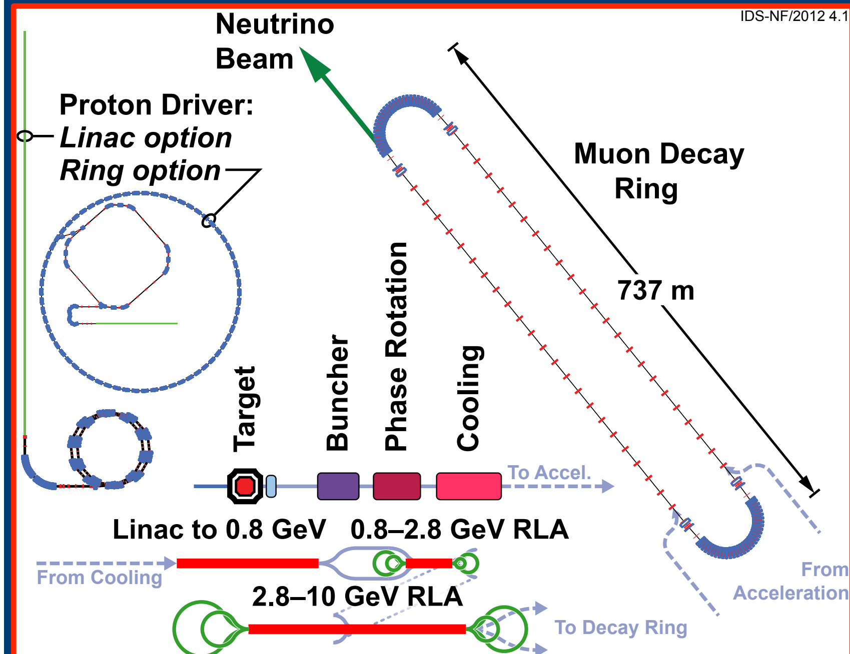
- Short Baseline Neutrino Factory
  - nuSTORM
    - Definitive measurement of sterile neutrinos
    - Precision ν_e cross-section measurements (systematics issue for long baseline SuperBeam experiments)
    - Could serve as a muon accelerator proving ground…

- Long Baseline Neutrino Factory with a Magnetized Detector
  - IDS-NF (International Design Study for a Neutrino Factory)
    - 10 GeV muon storage ring optimized for 1500-2500km baselines
    - "Generic" design (ie, not site-specific)
  - NuMAX (Neutrinos from a Muon Accelerator CompleX)
    - Site-specific: FNAL ⇨ SURF (1300km baseline)
    - 4-6 GeV beam energy
    - Can provide an ongoing short baseline measurement option
    - Detector options
      - Magnetized LAr is the goal
      - Magnetized iron provides equivalent CP sensitivities using ~3x the mass
  - Both options provide a route to high precision measurements in the ν sector with very well understood systematics

    ⇨ The advantage of high intensity "precision beams"

The Neutrino Factory

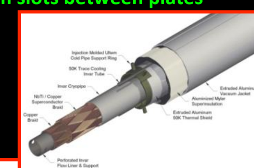
- IDS-NF

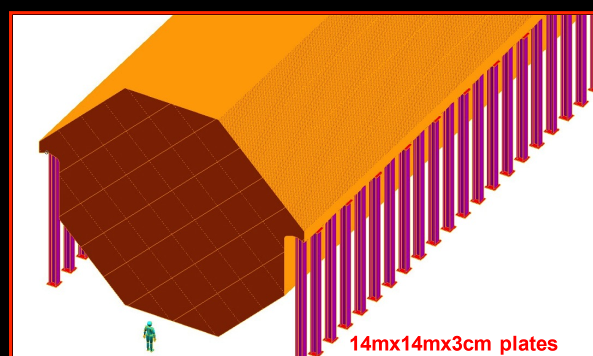


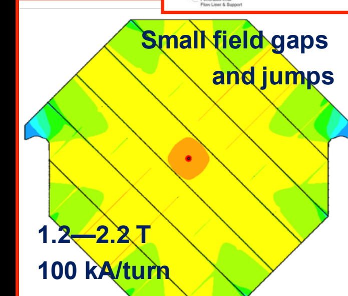
	Value
Accelerator facility	
Muon total energy	10 GeV
Production straight muon decays in 10^7 s	10^{21}
Maximum RMS angular divergence of muons in production straight	$0.1/\gamma$
Distance to long-baseline neutrino detector	1 500–2 500 km

Magnetized Iron Neutrino Detector (MIND):

- IDS-NF baseline:
  - Intermediate baseline detector:
    - 100 kton at 2500—5000 km
  - Magic baseline detector:
    - 50 kton at 7000—8000 km
  - Appearance of “wrong-sign” muons
  - Toroidal magnetic field > 1 T
    - Excited with “superconducting transmission line”
  - Segmentation: 3 cm Fe + 2 cm scintillator
  - 50-100 m long
  - Octagonal shape
  - Welded double-sheet
    - Width 2m; 3mm slots between plates





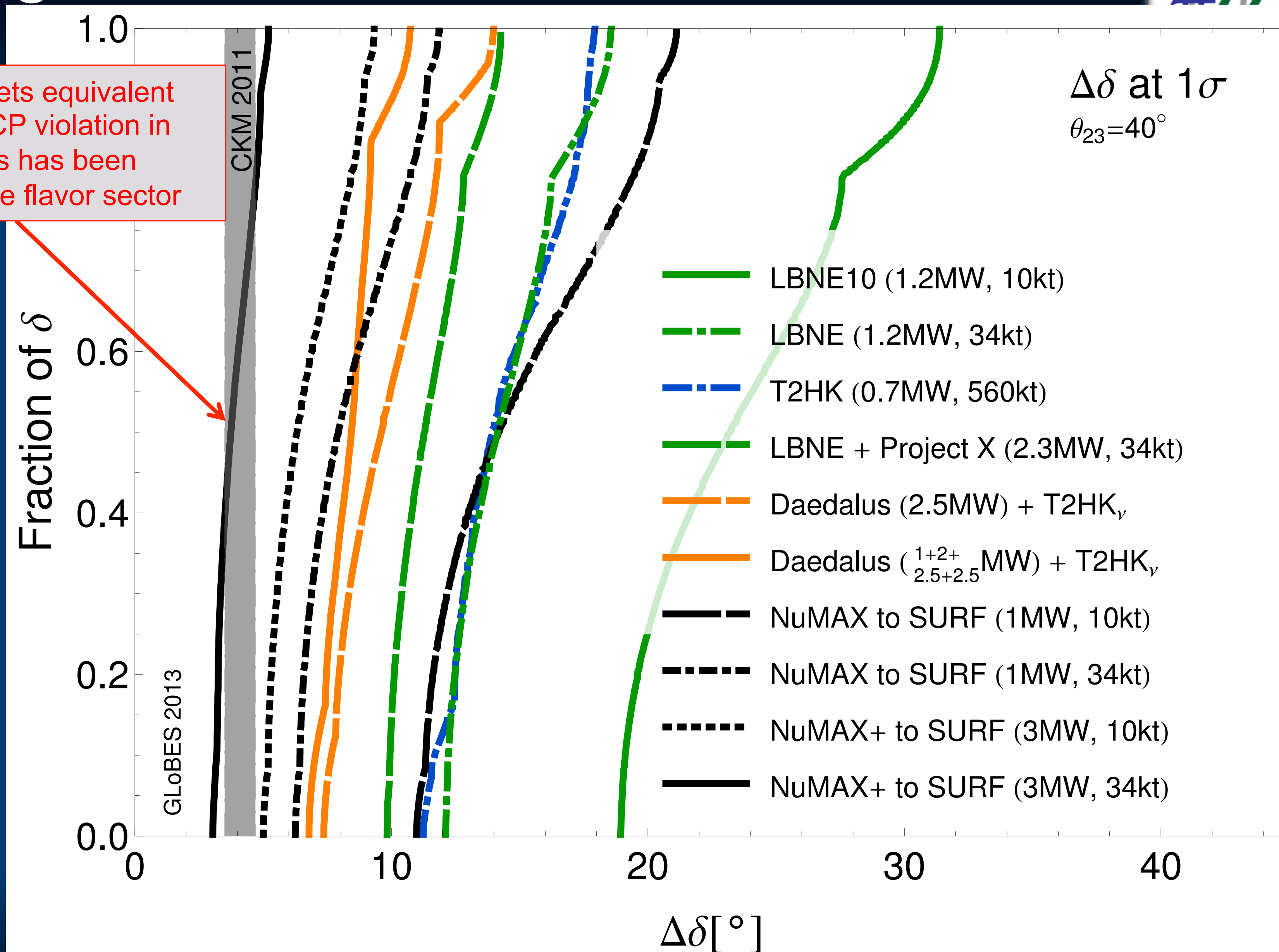


Bross, Soler

A Staged Plan with NuMAX at Fermilab

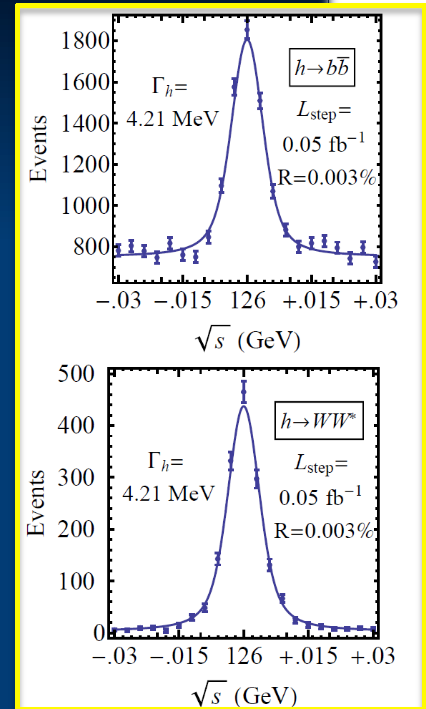
NuMAX+ targets equivalent sensitivity to CP violation in the ν sector as has been achieved in the flavor sector

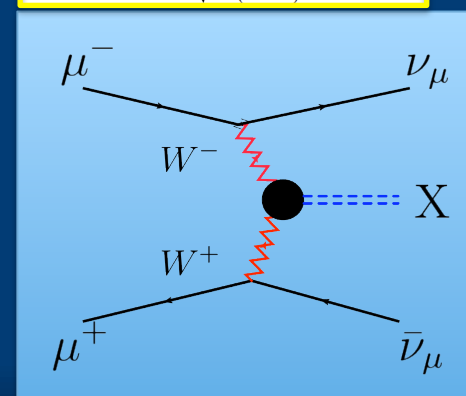
GLoBES Comparison of Potential Performance of the Various Advanced Concepts *(courtesy P. Huber)*



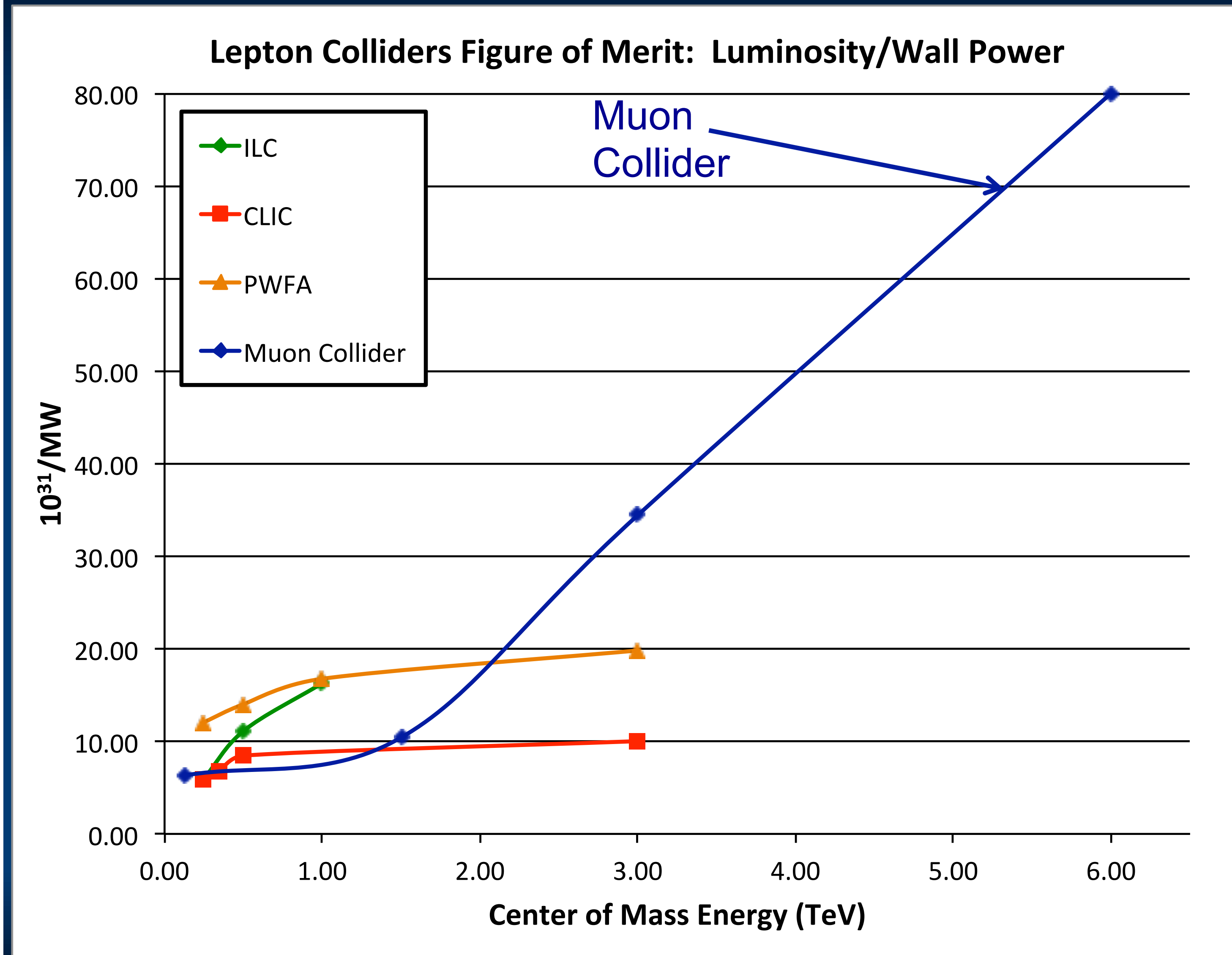
Physics Case for a Muon Collider

- Superb Energy Resolution
  - SM Thresholds and Higgs Factory operation
- At multi-TeV
  - Compact & energy efficient machine
  - Luminosity > 10^{34} cm^{-2} s^{-1}
  - Option for 2 detectors in the ring
- For $\sqrt{s}$ > 1 TeV: Fusion processes dominate
  ⇨ an Electroweak Boson Collider
  ⇨ a discovery machine complementary to a pp collider with $E_{pp} \approx 7E_{MC}$
- At >5TeV CoM, could provide Higgs self-coupling resolutions of <10%
- What if upcoming runs with the LHC shows evidence for a multi-TeV particle spectrum?





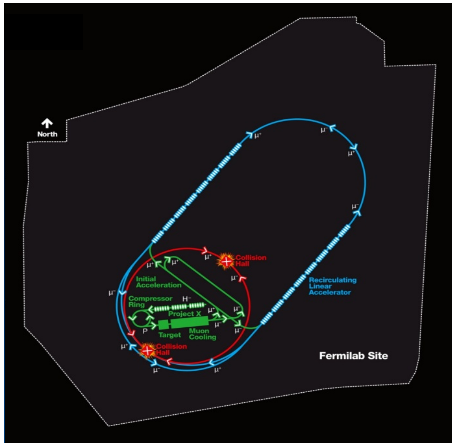
Luminosity Production Metric



Luminosity Metric:

$N_{det} \times L_{avg} / P_{tot}$

Muon Collider Parameters



Muon Collider Parameters

		Higgs Factory		**Top Threshold Options**		**Multi-TeV Baselines**		
Parameter	***Units***	*Startup Operation*	*Production Operation*	*High Resolution*	*High Luminosity*			*Accounts for Site Radiation Mitigation*
CoM Energy	TeV	0.126	0.126	0.35	0.35	1.5	3.0	6.0
Avg. Luminosity	$10^{34}cm^{-2}s^{-1}$	0.0017	0.008	0.07	0.6	1.25	4.4	12
Beam Energy Spread	%	0.003	0.004	0.01	0.1	0.1	0.1	0.1
Higgs* or Top^{+} Production/10^7sec		3,500*	13,500*	7,000^{+}	60,000^{+}	37,500*	200,000*	820,000*
Circumference	km	0.3	0.3	0.7	0.7	2.5	4.5	6
No. of IPs		1	1	1	1	2	2	2
Repetition Rate	Hz	30	15	15	15	15	12	6
β^*	cm	3.3	1.7	1.5	0.5	1 (0.5-2)	0.5 (0.3-3)	0.25
No. muons/bunch	10^{12}	2	4	4	3	2	2	2
No. bunches/beam		1	1	1	1	1	1	1
Norm. Trans. Emittance, ε_{TN}	π mm-rad	0.4	0.2	0.2	0.05	0.025	0.025	0.025
Norm. Long. Emittance, ε_{LN}	π mm-rad	1	1.5	1.5	10	70	70	70
Bunch Length, σ_s	cm	5.6	6.3	0.9	0.5	1	0.5	0.2
Proton Driver Power	MW	$4^{\#}$	4	4	4	4	4	1.6

Could begin operation with Project X Stage II beam

Exquisite Energy Resolution Allows Direct Measurement of Higgs Width

Success of advanced cooling concepts ⇨ several × 10^{32}

Site Radiation mitigation with depth and lattice design: ≤ 10 TeV

A Muon Accelerator Capabilities Technical Decision Tree

| Thru ~2020 | ~2020 | ~2025 | Late 2020s |

MAP Feasibility Study

Success with NF cooling demo (MICE)
⇨ Begin full technical design for a NF-based upgrade to LBNE

Failure ⇨ No path to NF and/or MC capabilities
⇨ **STOP NF/MC R&D Effort**

Success with MC Concepts
⇨ Begin the MC CDR and Advanced Systems Tests

If decide to pursue precision ν sector capabilities
⇨ **Begin the NF upgrade path**

CDR Completion and success Advanced Systems Tests
⇨ Begin full MC Engineering Design

Failure of Advanced Systems Tests
⇨ **Terminate MC development**

If LHC finds evidence for Supersymmetry AND when MC Engineering Design ready
⇨ **Decision point on a return to the EF with a Muon Collider** (which would build on the infrastructure deployed for a NF)

The Notional Timeline

- The preceding slide focuses on key decision points
  - Construction
    - ~2025: NF decision possible
    - Late 2020s: MC decision possible late in the next decade
    - Both decision points assume a successful MAP Feasibility Assessment
      - This requires a suitable funding profile
    - Assume a decade for construction approval and execution for each
      - Availability of various staging scenarios provides flexibility
    - Exact deployment schedule determined by budget profile
      And would be part of a global planning process…
  - Physics
    - Together these capabilities would provide a multi-decade set of capabilities (hence extending beyond the middle of the century)

The Key Choices

- The breadth of science that can be supported by a muon accelerator capability argues for continued support of the directed national accelerator R&D program (integrated with a global R&D effort) which is now in its 3rd year
  - Feasibility Assessment available by the end of the decade – in time for the next P5 round
- NF:
  The R&D would support future high precision capabilities with well-understood systematics
- MC:
  The R&D would prepare for the possibility that LHC running reveals the lowest states of a new particle spectrum

  Note that the MC may be the only viable route to a several TeV lepton collider capability in the next 20 years

Scope of international participation required:

- For machine and detectors
- Status of the arrangements
- How are the arrangements anticipated to develop over time?

ITEM 2 FROM P5

Scope of International Participation Required

- Staging scenarios assume
  - The US would host the machine effort
    - With strong international participation
  - Detector efforts (NF & MC) are assumed to be global

- The R&D effort already involves significant international connections and more are being pursued

- It is premature to speculate on the balance of involvement during a project until the feasibility assessment is complete

Current estimate of US contributions and why they are necessary?

How would the effort benefit US facilities and development of key US capabilities

What R&D is still required?

- Detailed scope
- Required resources
- Projected timeline

How are the MC and NF connected (both necessarily and optionally)?

If this is a multi-agency project, what are the envisioned roles and division of scope?

ITEM 3 FROM P5

R&D Effort

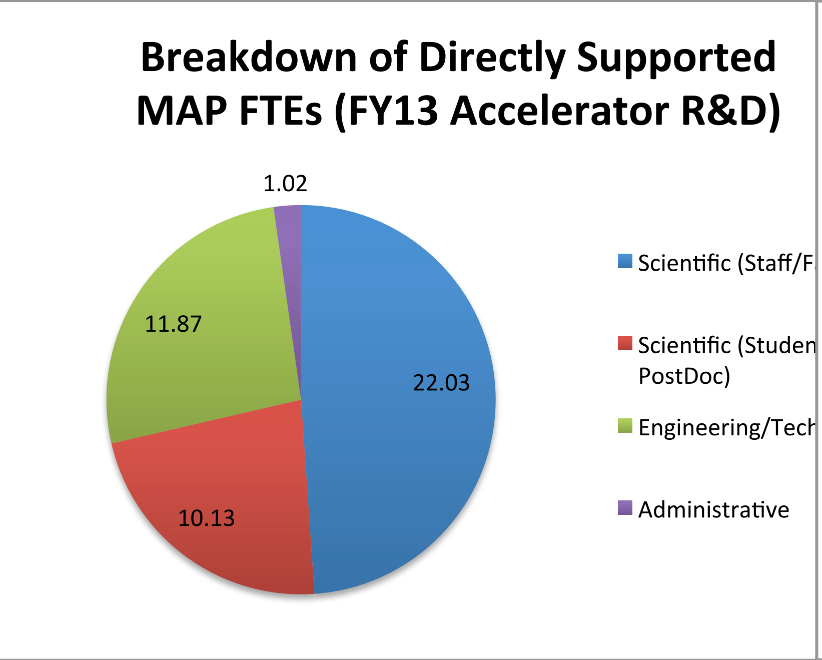
- Scope – ***Note that MAP is constituted as a directed Accelerator Technology R&D Effort to demonstrate feasibility***
  - Provide:
    - Specifications for all required technologies
    - Baseline design concepts for each accelerator system (see block diagram to follow)
  - For novel technologies:
    - Carry out the necessary design effort and R&D to assess feasibility
    - Note: a program of advanced systems R&D is anticipated ***after*** completion of the feasibility assessment
  - Ongoing Technology R&D and feasibility demonstrations include:
    - MuCool Test Area experimental program (FNAL): RF in high magnetic fields
    - The Muon Ionization Cooling Experiment (MICE@RAL):
      - Demonstration of emittance reduction
      - Validation of cooling channel codes
    - Advanced magnet R&D
      - Very high field magnets (cooling channel and storage rings)
      - Rapid cycling magnets for acceleration of short-lived beams

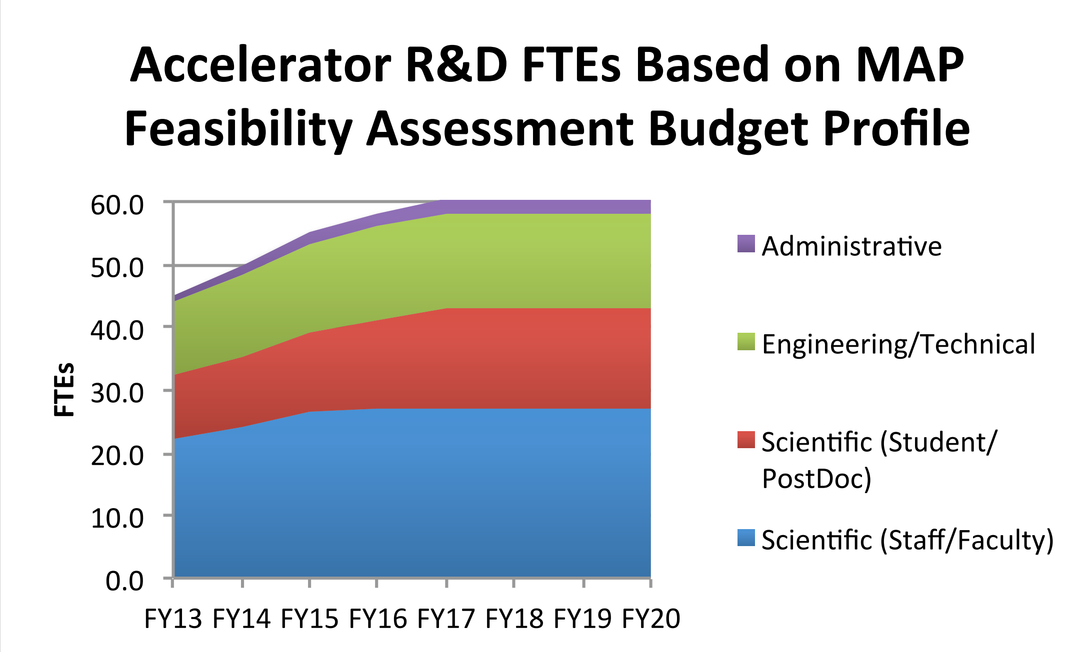
See supporting slides at end

R&D Effort (cont'd)

Projected Resources – US Accelerator R&D from DOE HEP

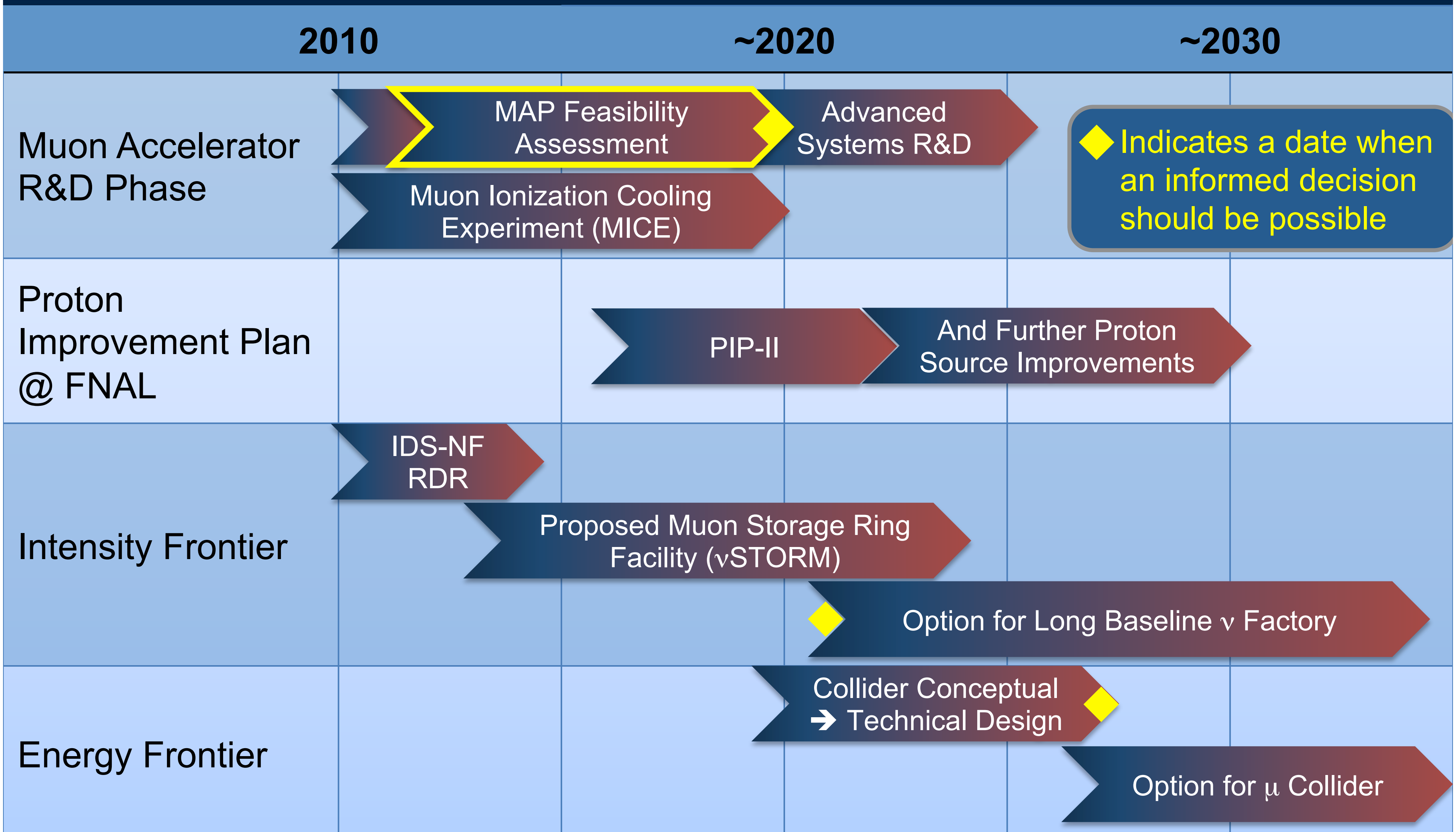
- Feasibility Phase ONLY
- A subsequent technical design phase would likely require at least a doubling of resources for a 3-5 year period.





- NF Detector/Physics – supported globally by IDS-NF (48 institutions, 136 authors)
- MC Detector/Physics – not formally supported (MAP funding ⇨ Accel R&D).
  - In FY13, ≤2 FTEs from Fermilab along with some community involvement.
  - Need ~10-20% (ie, 5-10 FTEs) of the accelerator effort required to validate detector capabilities.

MAP Timeline ⇨ Provide Informed Decision Points



NF & MC Connections

- Key connections were shown in the block diagrams in slide 4
- Conclusions:
  - Development of the foundation for either capability (ie, proton driver, target system, front end) supports the other, thus offering significant advantages
  - In terms of cost effectiveness, staging options, and potential support for two of the major thrusts in HEP, integrating both options for the R&D phase is the most desirable approach

Multi-agency Issues

- MAP R&D Program is supported by DOE HEP
  - NSF has provided some added support for
    - SRF
    - MICE Experiment

- A successful transition to a project would assume a multi-agency model

Estimate the number of physicists needed by project phase, including operations and data analysis

ITEM 4 FROM P5

Physicist Requirements

- Feasibility Phase – see slide 21
- Construction Phase
  - A staged approach would enable much of the effort to be accomplished with existing US accelerator resources
- The NF supports a major detector at SURF
  - To 1st order would appear as an extension of ongoing upgrade and operations needs on the detector side
- A MC option with 2 detectors would be expected to have a collaboration of O(1000) physicists/detector

⇨ Both would require accelerator support at the level of the Fermilab Accelerator Division for operations

Any other information we wish to communicate to P5

ITEM 5 FROM P5

Concluding Remarks

- Our accelerator-based HEP program in the US is reliant on accelerators that were deployed 15-40 years ago. For more than a decade, the focus has been on operations and experiments, as well as the possibility of new green field facilities

- A major question for this P5 is whether there is room to plan for the possibility of significant upgrades to the US HEP accelerator capabilities.

  Muon accelerator capabilities offer tremendous promise for the field and would be well-suited for implementation at our domestic HEP facility.

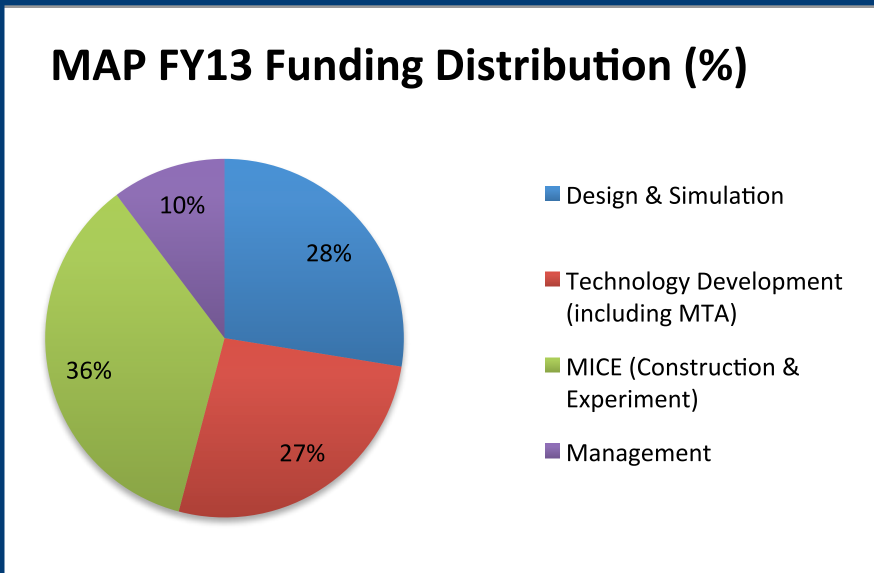
- A recommendation from the Accelerator Capabilities report:

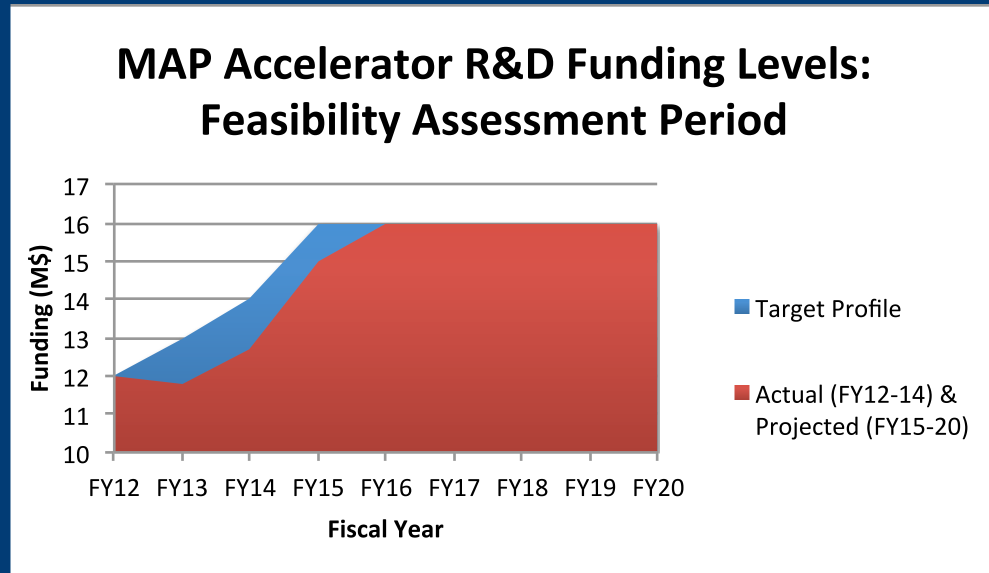
  A vigorous, integrated U.S. research program toward demonstrating feasibility of a muon collider is highly desirable. The current funding level is inadequate to assure timely progress.

SUPPORTING SLIDES

MAP Budget Profile

- MAP budget is dominated by demonstration efforts for the key technologies
  - At present, the most significant investment is towards muon ionization cooling technologies and demonstrations





  - The length of the timeline is determined by maximum annual budget and completing key demonstrations (eg, MICE, RF and high field magnet prototypes)

The MAP Collaboration

- Participants in FY14
  - People:

    ~150 individuals

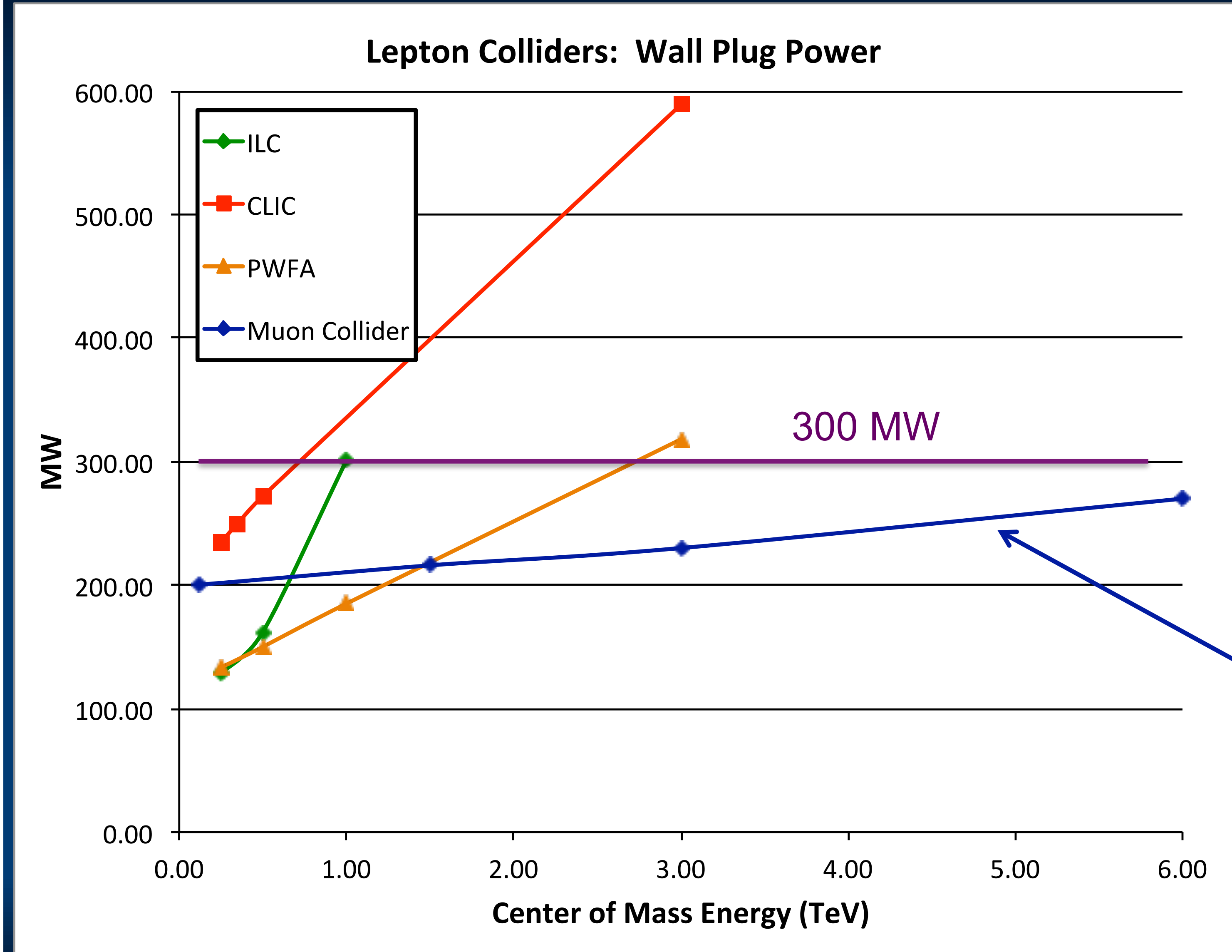
    ~50 FTEs
  - International Efforts:
    - International Design Study for a Neutrino Factory (IDS-NF)
    - Muon Ionization Cooling Experiment (MICE at RAL)
  - Participating Institutions (21)

    FNAL (host), ANL, BNL, Cornell, CMU, Chicago, ICL, IIT, JLAB, LBNL, Mississippi, Muons Inc, ORNL, PBL, Princeton, SLAC, SUNY-SB, UC-Berkeley, UCLA, UC-Riverside, VT

Muon Collider Whitepapers

- **SNOW13-00101 Enabling Intensity and Energy Frontier Science with a Muon Accelerator Facility in the U.S.: A White Paper Submitted to the 2013 U.S. Community Summer Study of the Division of Particles and Fields of the American Physical Society** arxiv: 1308.0494
- **SNOW13-00072 Discriminators of 2 Higgs Doublets at the LHC14, ILC and MuonCollider(125): A Snowmasss White Paper** arxiv: 1307.3676
- **SNOW13-00033 The Muon Collider as a H/A Factory** arxiv: 1306.2609
- **SNOW13-00113 Muon Collider Higgs Factory for Snowmass 2013** arxiv: 1308.2143

Wall Plug Power Estimates



Estimate assumes a base 70MW Facility Power requirement as in LC analyses.

Muon Collider

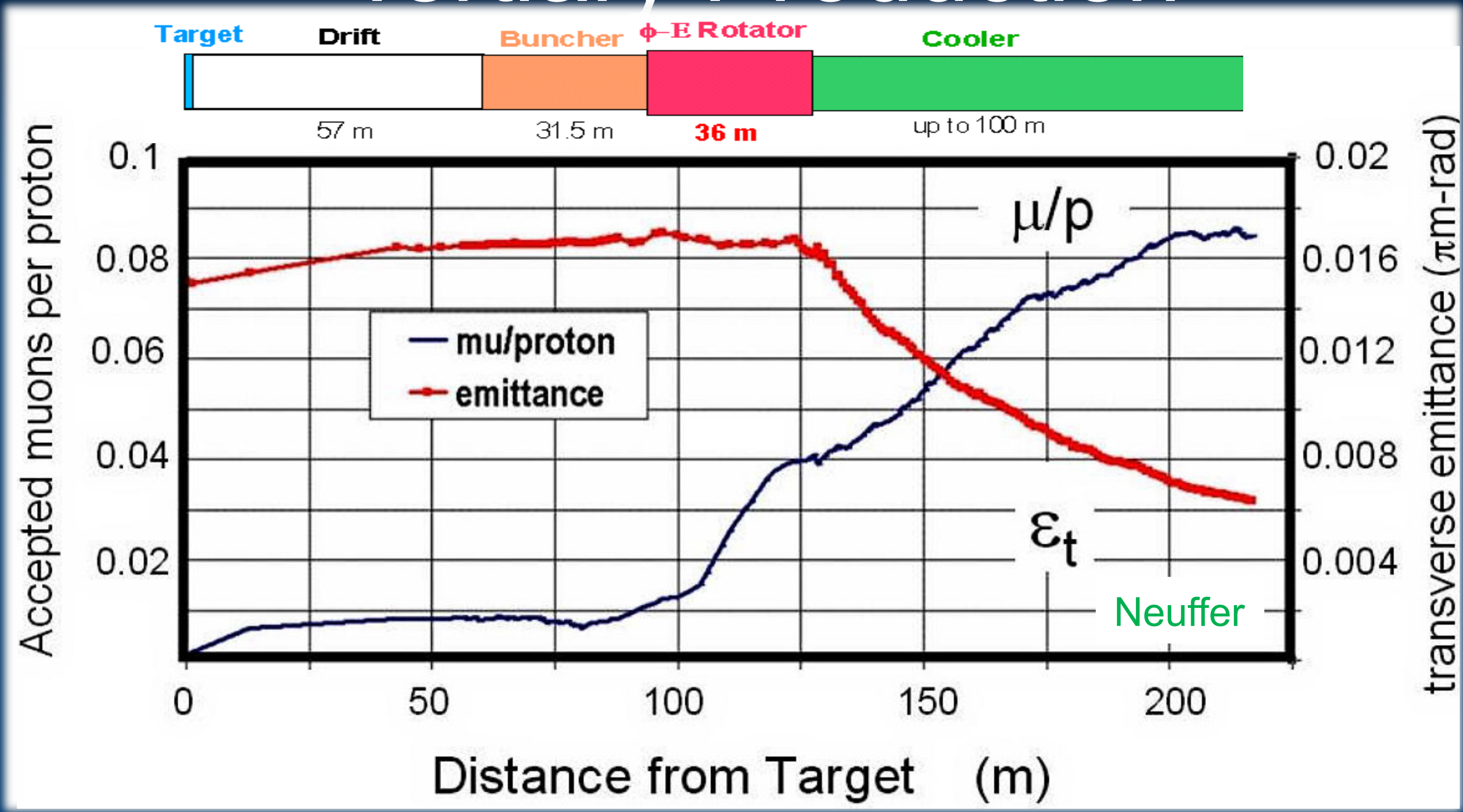
The Initial Baseline Selection Process and Technology R&D Program

SUPPORTING SLIDES

MAP Initial Baseline Selection Process

- Now to 2016:
  - Explore, develop, and select the **Initial Baseline Design (IBS)** of all accelerator subsystems
    - Clear specifications are absolutely critical to the technology demonstrations that are being undertaken to establish the feasibility of high intensity muon accelerators
    - The coupling between design and technology is clearly iterative
    - However, given the knowledge that we presently have, it is crucial to clearly define the design concepts for individual systems
  - To enhance the quality of the designs, the IBS process will focus primarily on a site-specific implementation at Fermilab which would build on the superconducting linac upgrade presently being planned
    - It will also focus on specifications that are compatible with the conclusions of the Muon Accelerator Staging Study (MASS)
- In the 2016-2020 timeframe, will launch the next set of feasibility R&D activities (on the basis of the IBS-specified designs)

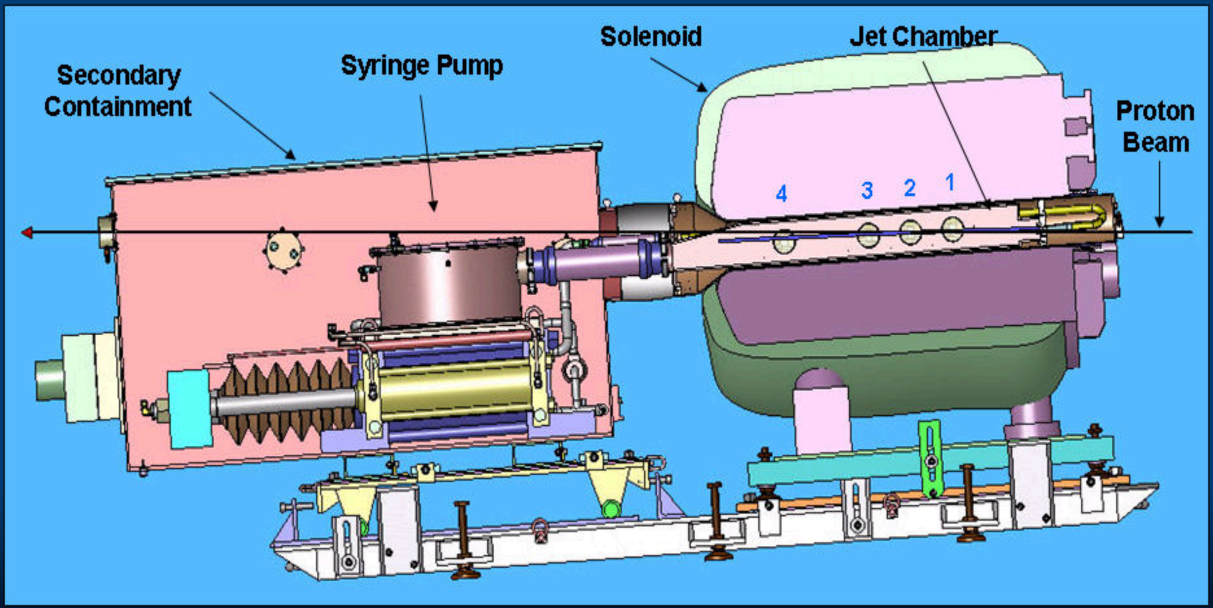
Technology Challenges – Tertiary Production

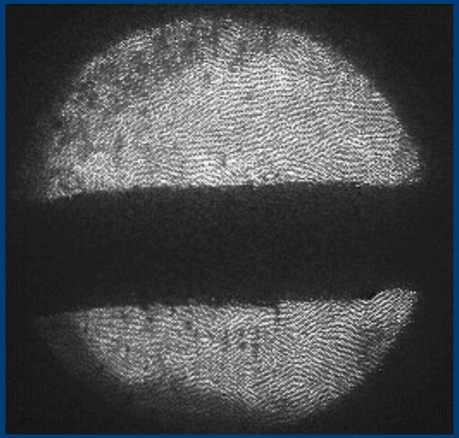


- A multi-MW proton source, *i.e.,* the extension of PIP-II, will enable O(10^{21}) muons/year to be produced, bunched and cooled to fit within the acceptance of an accelerator.

Key Technologies - Target

- The MERIT Experiment at the CERN PS
  - Demonstrated a 20m/s liquid Hg jet injected into a 15 T solenoid and hit with a 115 KJ/pulse beam!
    - ⇨ Jets could operate with beam powers up to **8 MW** with a repetition rate of 70 Hz
- MAP staging aimed at initial 1 MW target





Hg jet in a 15 T solenoid with measured disruption length ~ 28 cm

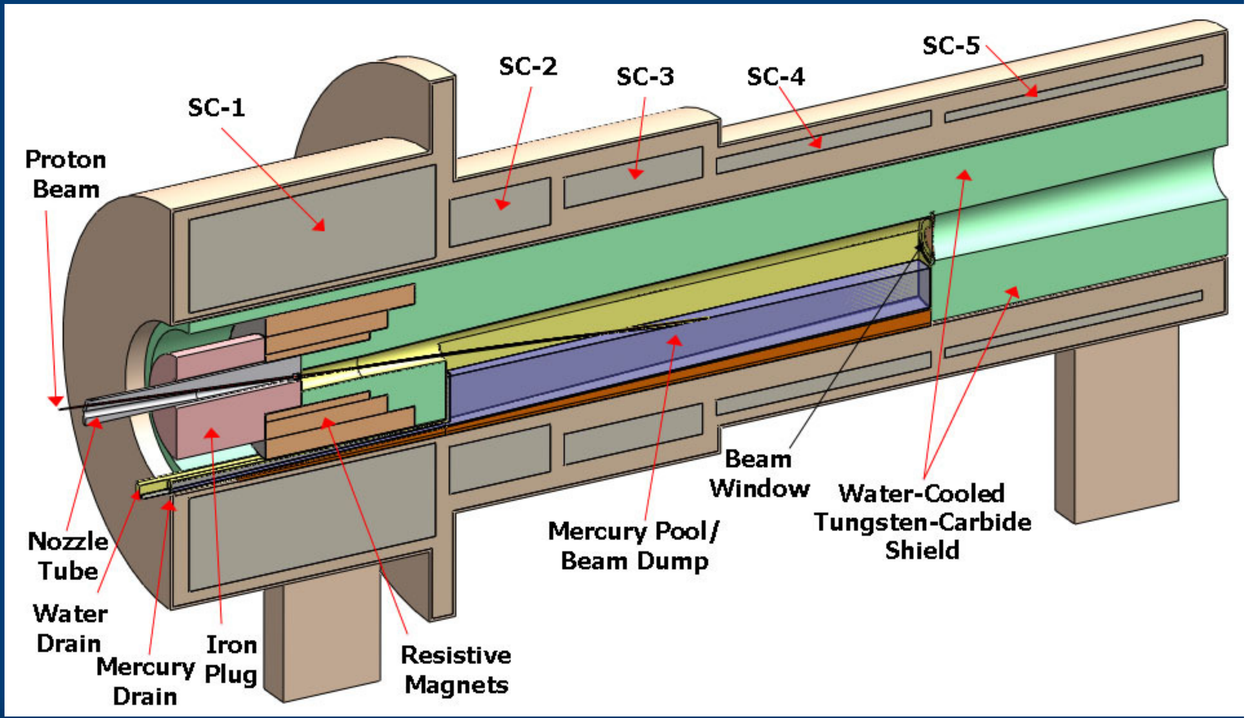
Technology Challenges – Capture Solenoid

- A Neutrino Factory and/or Muon Collider Facility requires challenging magnet design in several areas:
  - Target Capture Solenoid (15-20T with large aperture)

$E_{stored} \sim 3$ GJ

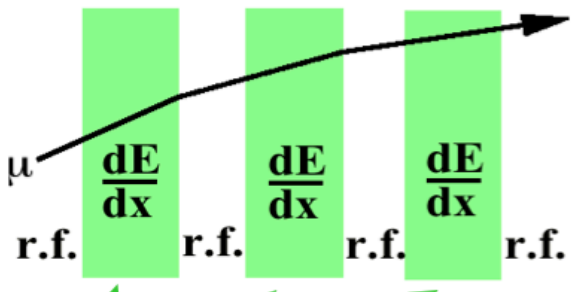
O(10MW) resistive coil in high radiation environment

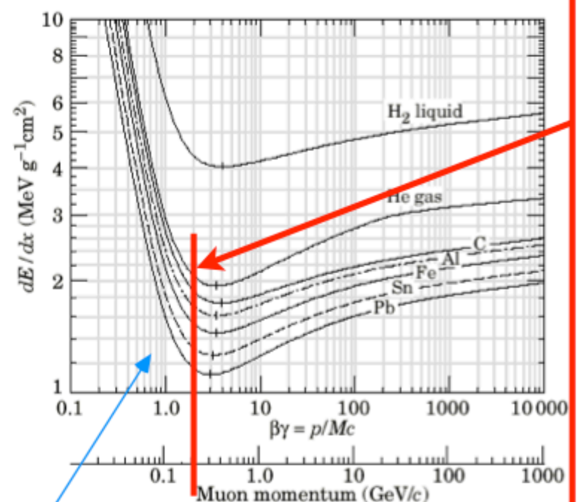
Possible application for High Temperature Superconducting magnet technology



Ionization Cooling

- Muons cool via dE/dx in low-Z medium





- **ionization minimum is ≈ optimal working point:**
  - longitudinal +ive feedback at lower p
  - straggling & expense of reacceleration at higher p

– Absorbers:

$$\begin{cases} E \rightarrow E - \left\langle \dfrac{dE}{dx} \right\rangle \Delta s \\ \theta \rightarrow \theta + \theta^{rms}_{space} \end{cases}$$

ionization energy loss

multiple Coulomb scattering

- 2 competing effects ⇒ ∃ equilibrium emittance

– RF cavities between absorbers replace ΔE

– Net effect: reduction in $p_\perp$ at constant $p_\parallel$, i.e., transverse cooling

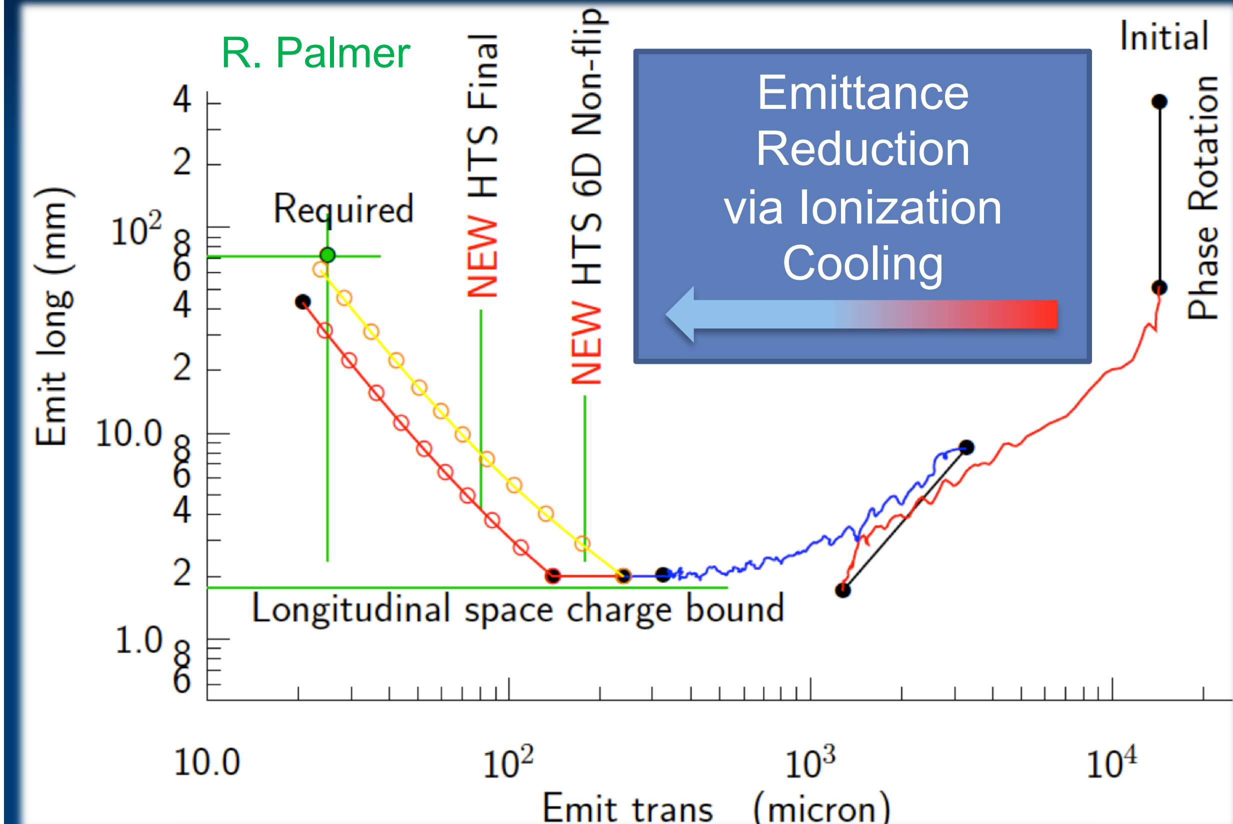
$$\frac{d\epsilon_N}{ds} \approx -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \text{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

(emittance change per unit length)

D. Kaplan

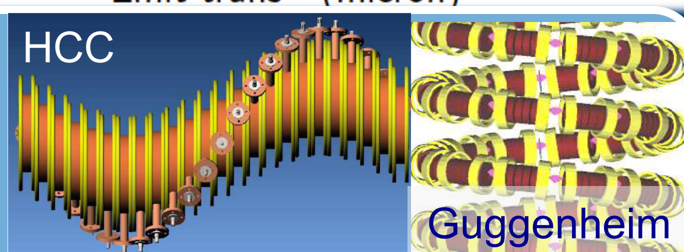
Technology Challenges - Cooling

Development of a cooling channel design to reduce the 6D phase space by a factor of $O(10^6)$ $\longrightarrow$ MC luminosity of $O(10^{34})$ $cm^{-2}\ s^{-1}$



- Some components beyond state-of-art:
  - Very high field HTS solenoids (≥30 T)
  - High gradient RF cavities operating in multi-Tesla fields

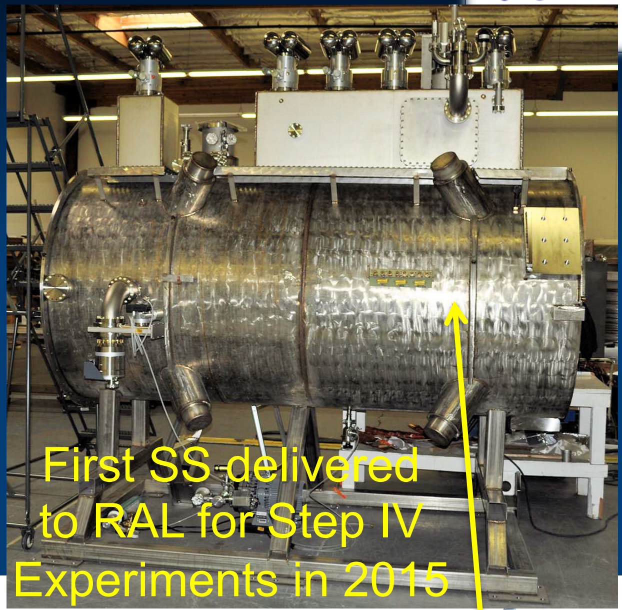
Cooling Channel Concepts



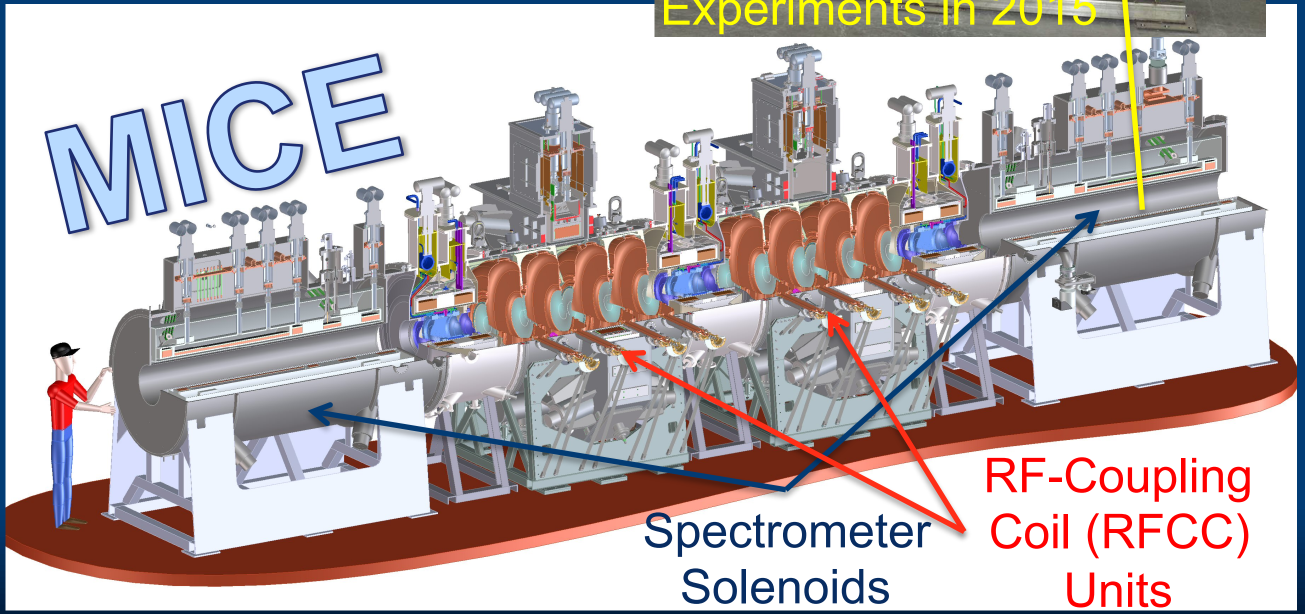
The program targets critical magnet and cooling cell technology demonstrations within its feasibility phase.

Technology Challenges - Cooling

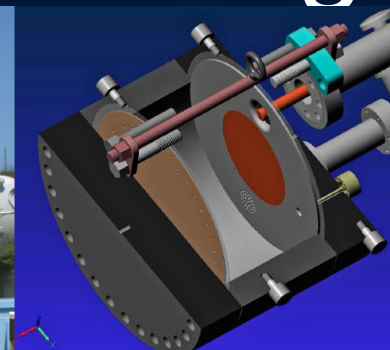
- Tertiary production of muon beams
  - Initial beam emittance intrinsically large
  - Cooling mechanism required, but no radiation damping
- Muon Cooling ⇨ Ionization Cooling
  - dE/dx energy loss in materials
  - RF to replace p_{long}

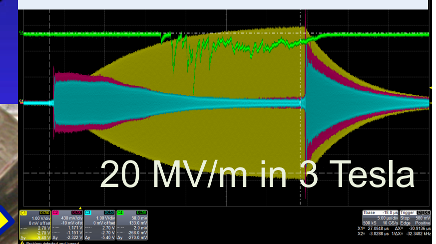


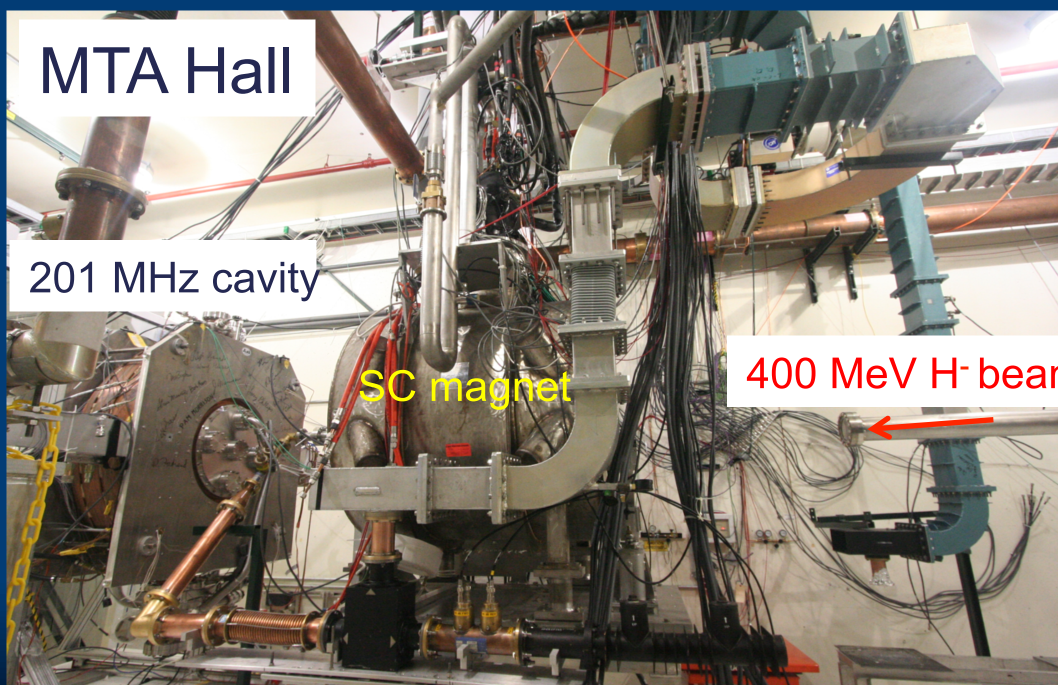
The Muon Ionization Cooling Experiment: Demonstrate the method and validate our simulations

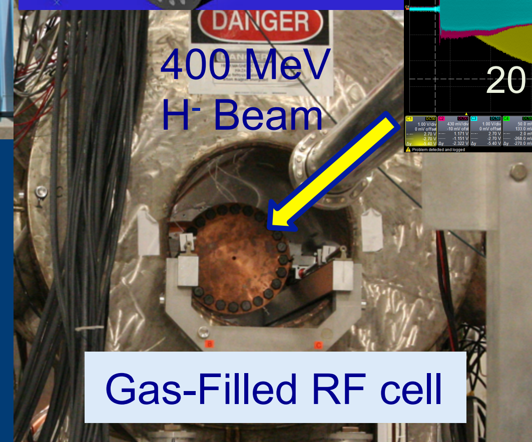


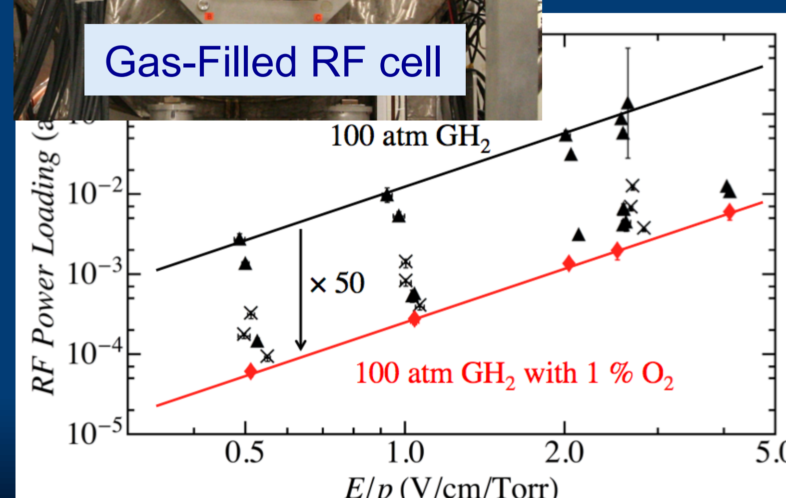
Elements of the R&D Program



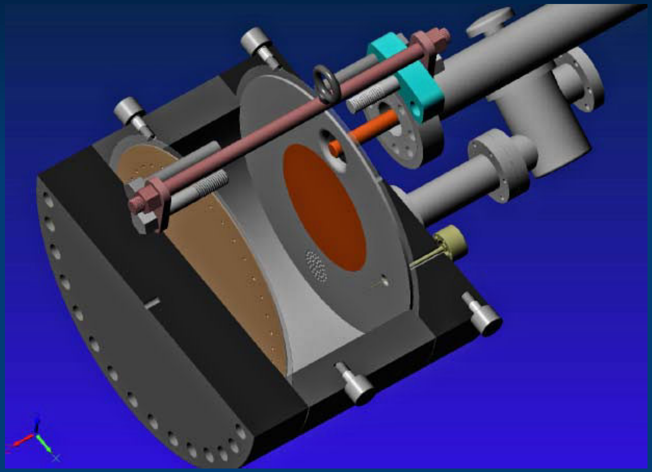






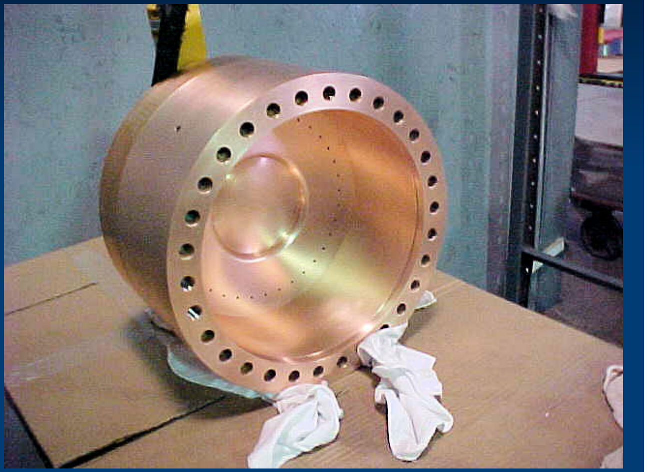


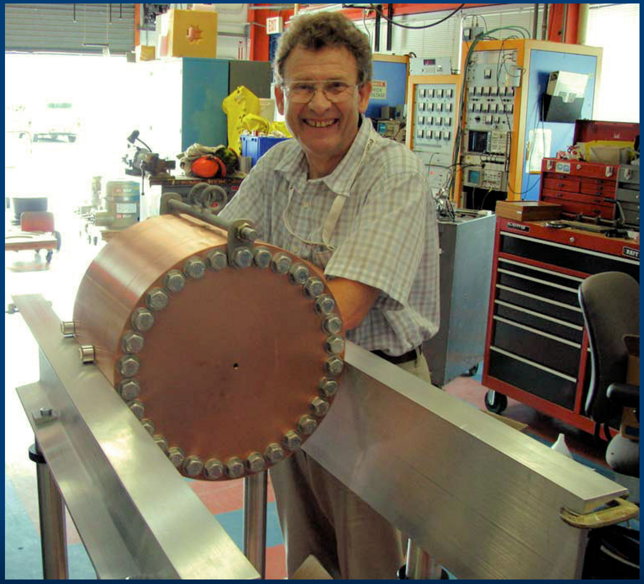
Recent Progress – Vacuum RF



All-Seasons Cavity

(designed for both vacuum and high pressure operation)

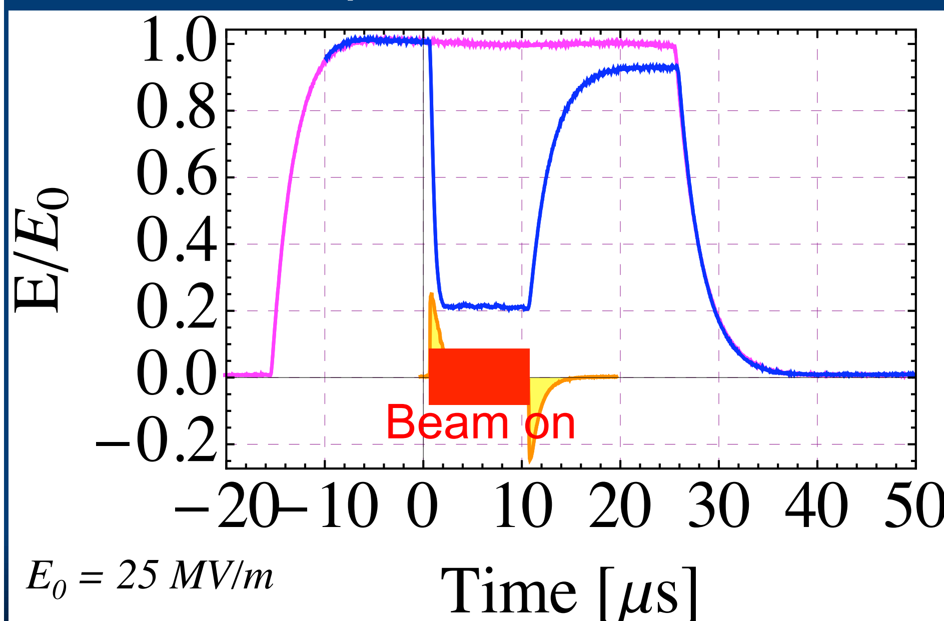


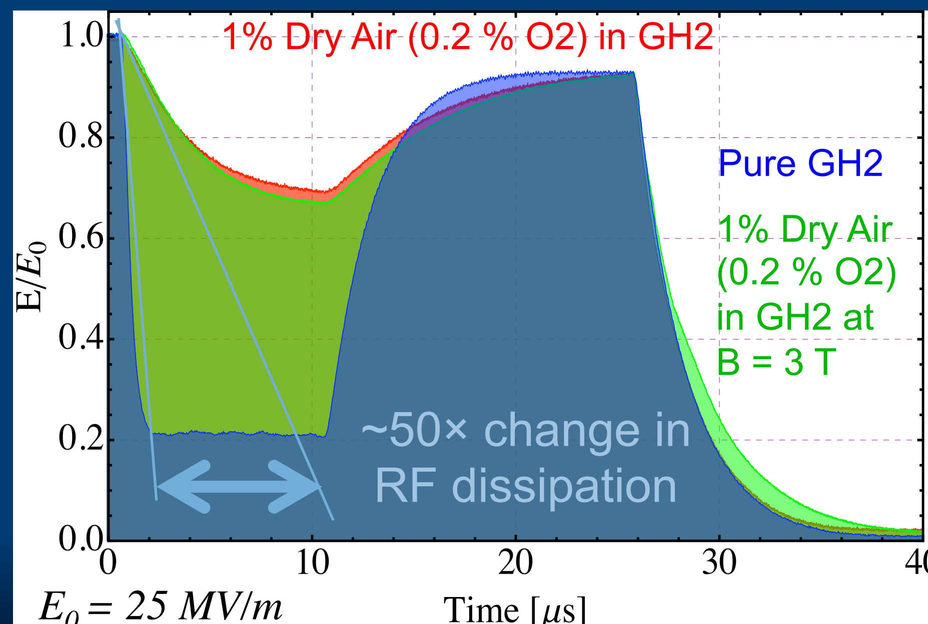


- Now operated in magnetic fields up to 5T:
  - Gradients > 20 MV/m
- Demonstrates possibility of successful operation of vacuum cavities in magnetic fields with careful design
- Successor design (the *805 MHz Modular Cavity*) will be ready for testing during FY14
- *Also progress on alternative cavity materials*

Recent Progress - High Pressure RF

- Gas-filled cavity
  - Can moderate dark current and breakdown currents in magnetic fields
  - Can contribute to cooling
  - Is loaded, however, by beam-induced plasma
- Electronegative Species
  - Dope primary gas
  - Can moderate the loading effects of beam-induced plasma by scavenging the relatively mobile electrons





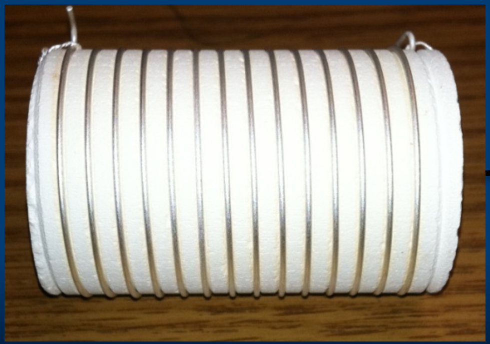
Recent Progress - High Field Magnets

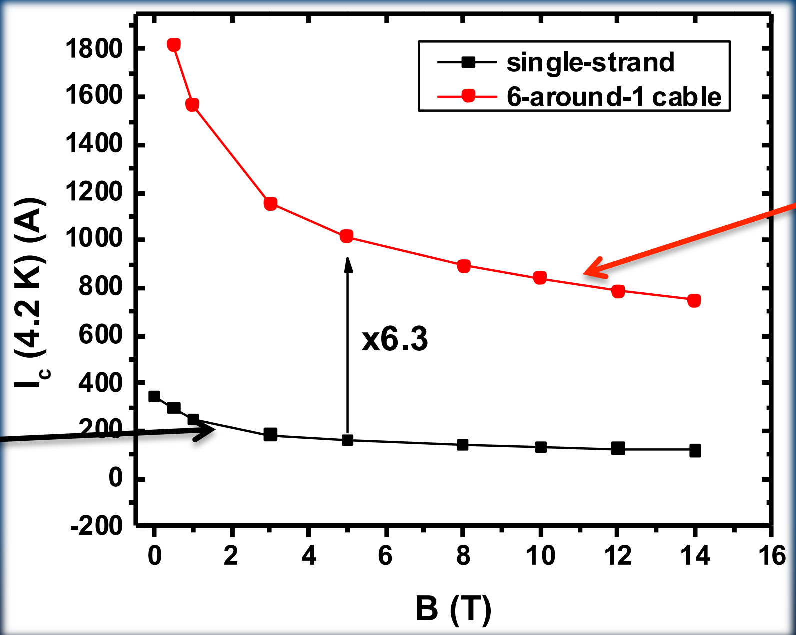
Progress towards a demonstration of a final stage cooling solenoid:

- Demonstrated 15+ T (16+ T on coil)
  - ~25 mm insert HTS solenoid
  - BNL/PBL YBCO Design
  - Highest field ever in HTS-only solenoid (by a factor of ~1.5)
- Developing a test program for operating HTS insert + mid-sert in an external solenoid ⇨ >30 T

BSCCO-2212 -

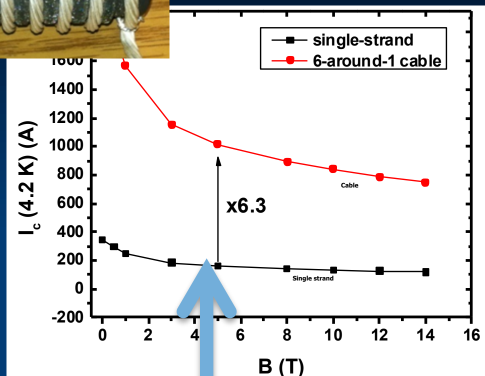
- New cable fabrication methods with demonstrated J_E
- Hyperbaric processing to avoid strand damage





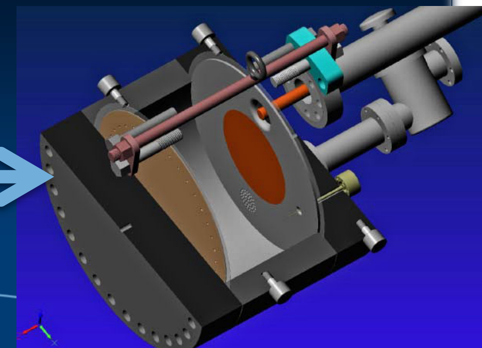
Multi-strand cable utilizing chemically compatible alloy and oxide layer to minimize cracks

Cooling Channel R&D Effort



Successful Operation of 805 MHz "All Seasons" Cavity in 5T Magnetic Field under Vacuum

MuCool Test Area/Muons Inc



Breakthrough in HTS Cable Performance with Cables Matching Strand Performance

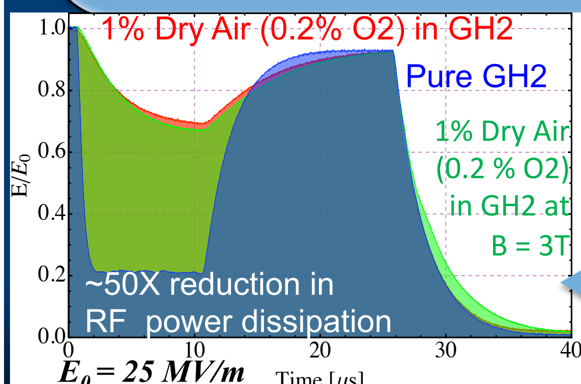
FNAL-Tech Div
T. Shen-Early Career Award

The Path to a Viable Muon Ionization Cooling Channel

World Record HTS-only Coil

15T on-axis field
16T on coil

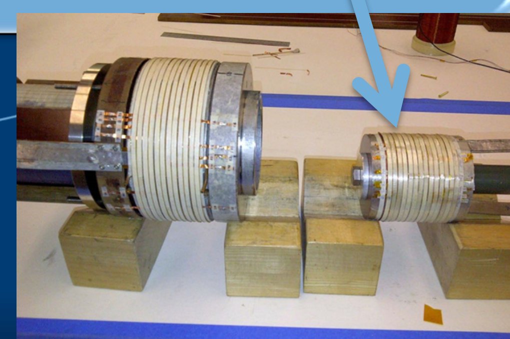
PBL/BNL



Demonstration of High Pressure RF Cavity <u>in 3T Magnetic Field with Beam</u>

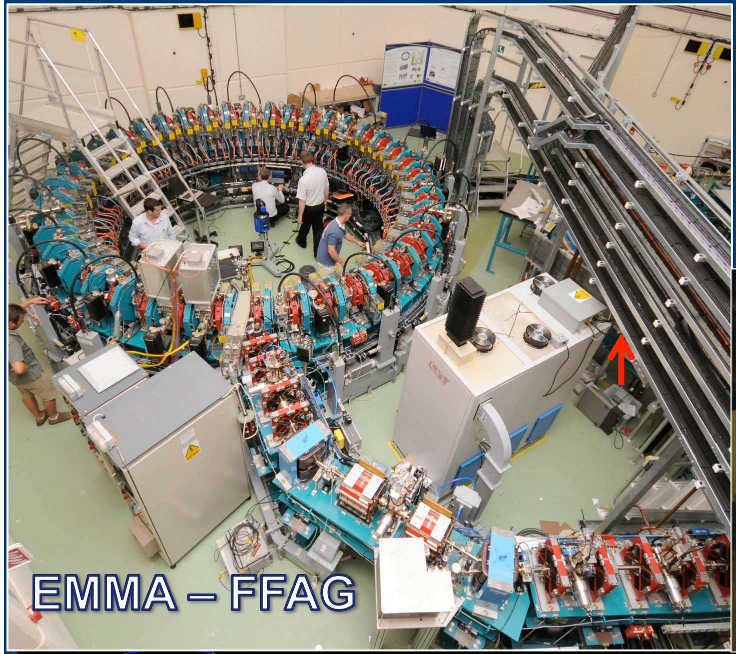
Extrapolates to μ-Collider Parameters

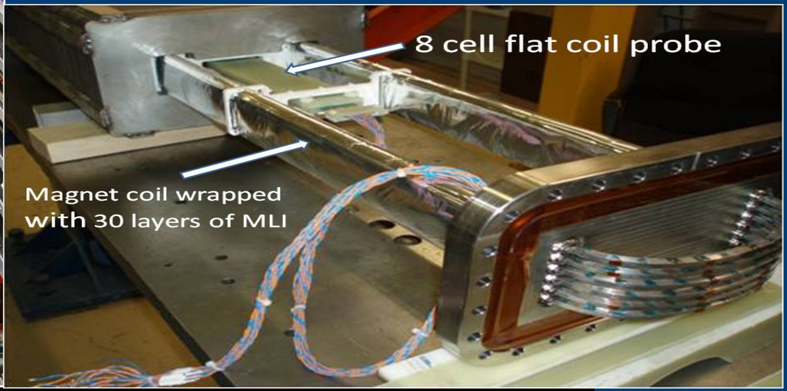
MuCool Test Area



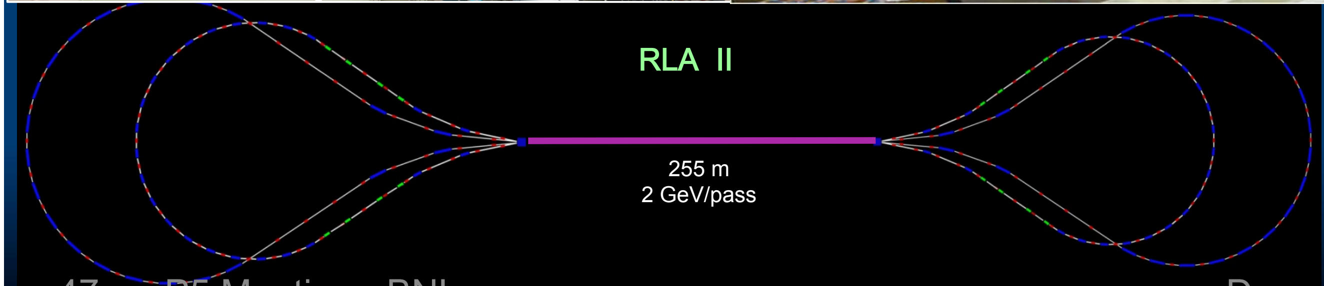
Technology Challenges - Acceleration

- Muons require an ultrafast accelerator chain
  - ⇨ *Beyond the capability of most machines*
- Solutions include:
  - Superconducting Linacs
  - Recirculating Linear Accelerators (RLAs)
  - Fixed-Field Alternating-Gradient (FFAG) Machines
  - Rapid Cycling Synchrotrons (RCS)



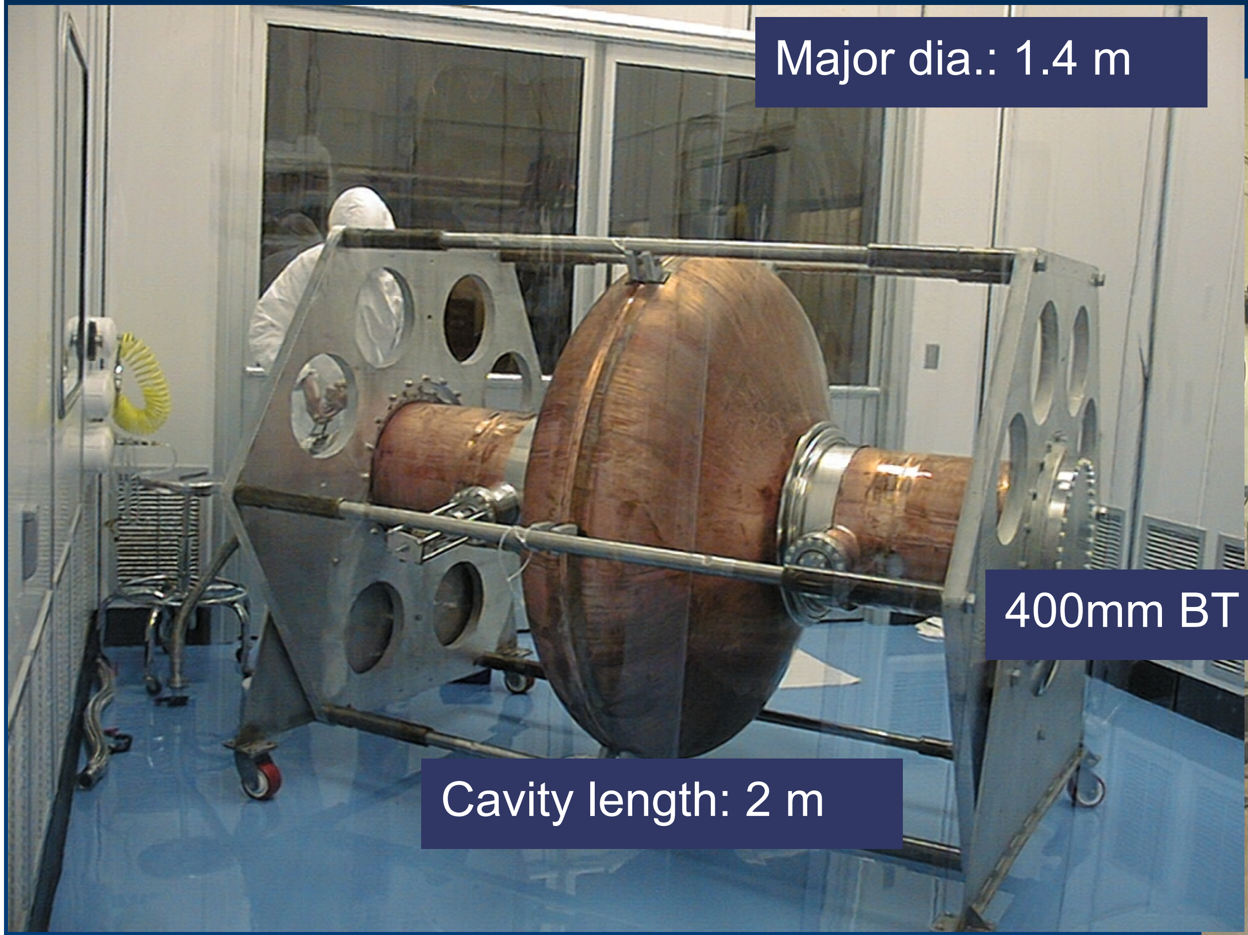


RCS requires 2 T p-p magnets at f = 400 Hz (U Miss & FNAL)

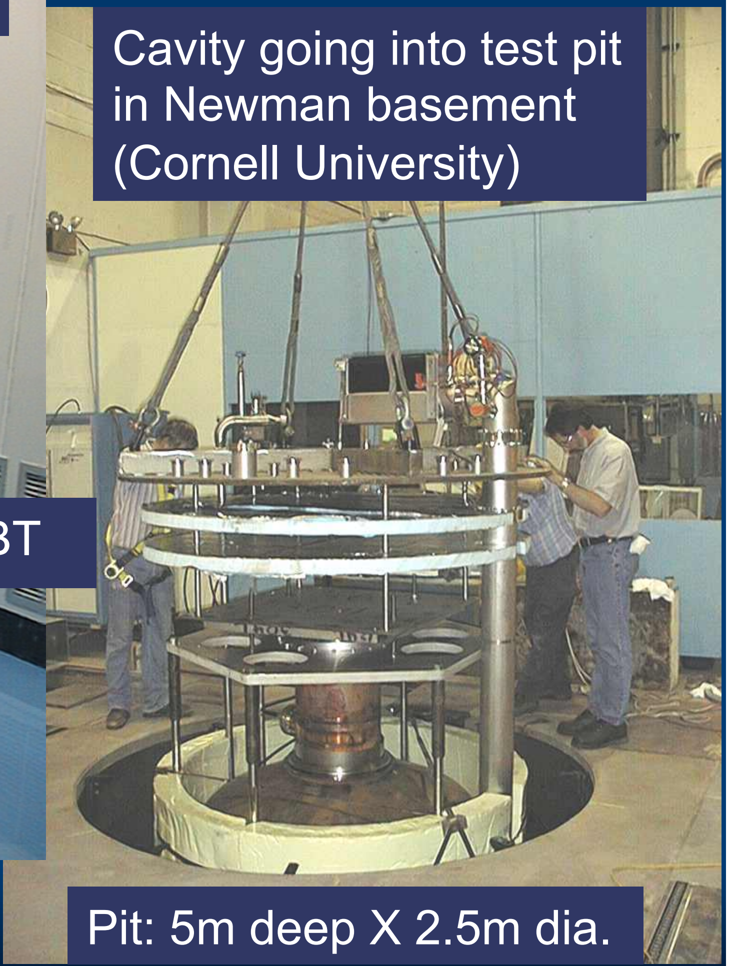


JEMMRLA Proposal: JLAB Electron Model of Muon RLA with Multi-pass Arcs

Superconducting RF Development

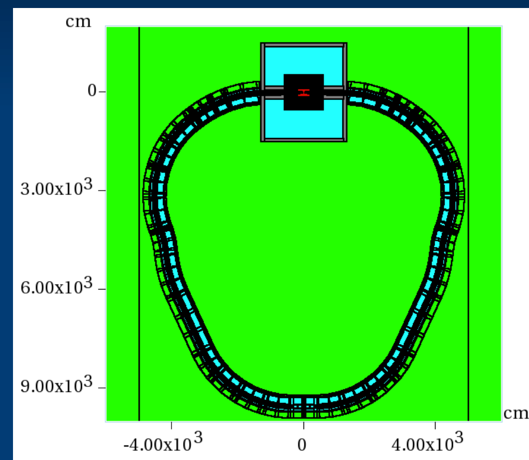


201 MHz SCRF R&D

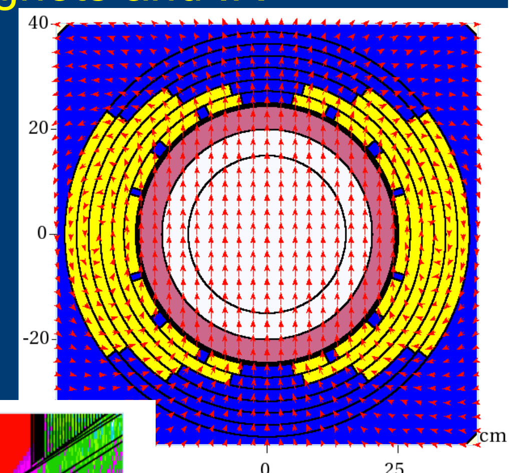


Technology & Design Challenges – Ring, Magnets, Detector

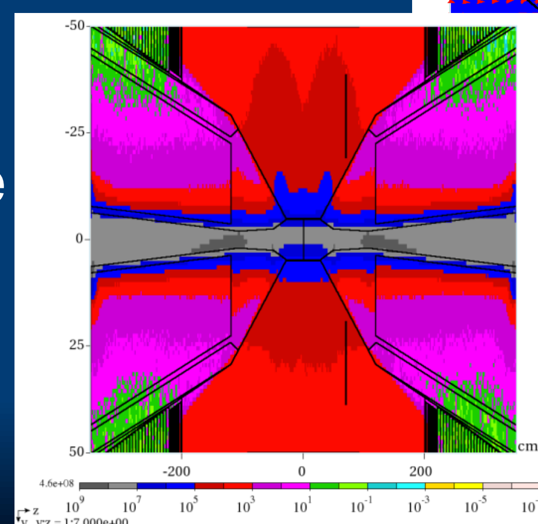
- Emittances are relatively large, but muons circulate for ~1000 turns before decaying
  - Lattice studies for 126 GeV, 1.5 & 3 TeV CoM



MARS energy deposition studies for Higgs Factory magnets and IR



- High field dipoles and quadrupoles must operate in high-rate muon decay backgrounds
  - Magnet designs under study



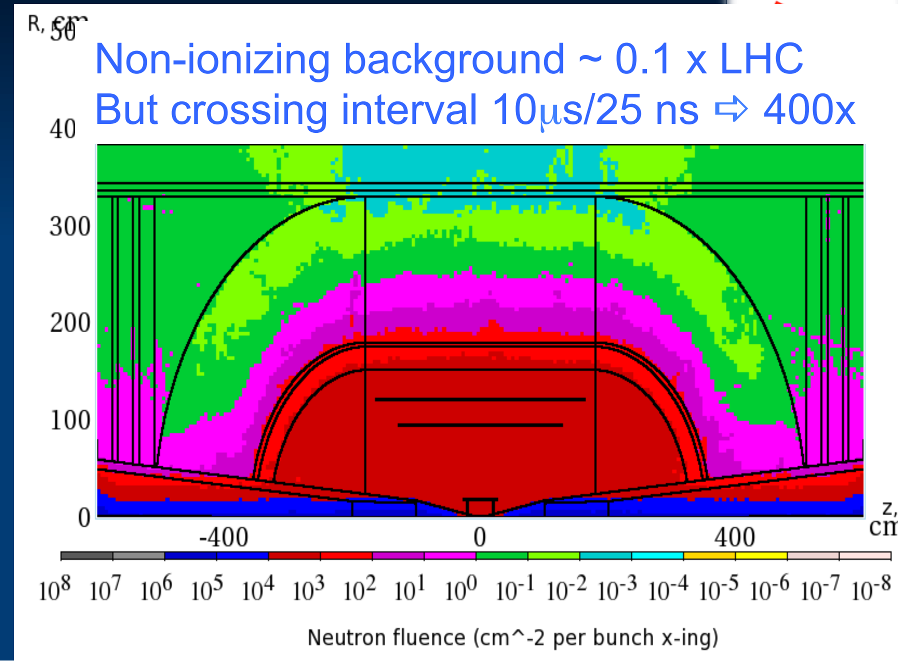
- Detector shielding & performance
  - Initial studies for 1.5 TeV, then 3 TeV and now 126 GeV
  - Shielding configuration
  - MARS background simulations

Backgrounds and Detector

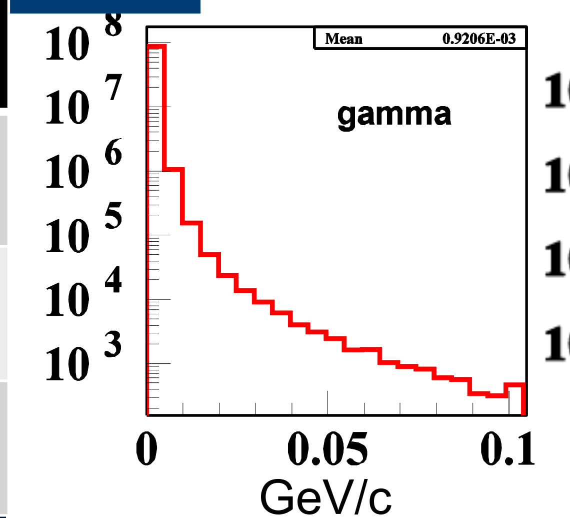
Much of the background is soft and out of time

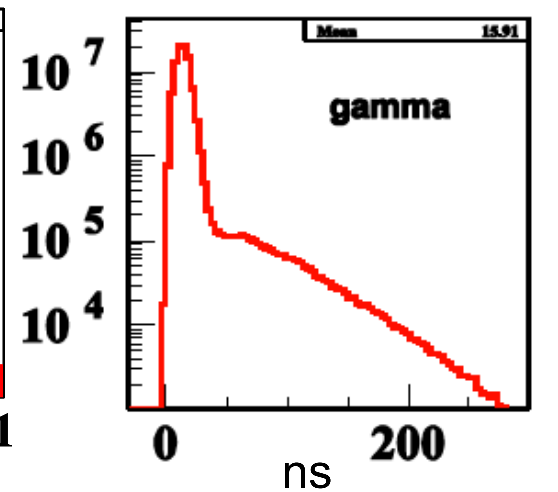
- Nanosecond time resolution can reduce backgrounds by three orders of magnitude

Requires a fast, pixelated tracker and calorimeter.



	Cut	Rejection
Tracker hits	1 ns, dedx	9×10^{-4}
Calorimeter neutrons	2 ns	2.4×10^{-3}
Calorimeter photons	2 ns	2.2×10^{-3}

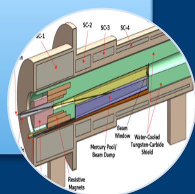




Overview of MAP Magnet Pull

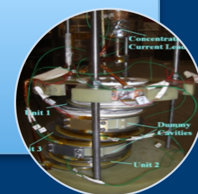
- Characteristics:
  - High field (15-20T)
  - Large bore (meter-scale)
  - Intense radiation environment – NC or HTS insert coil

Capture Solenoid for Simultaneous mu+ & mu- Beams



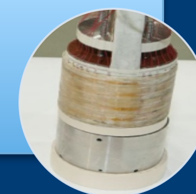
- Characteristics:
  - Solenoid-based cooling channel (LH_2/LiH absorbers)
  - RF cavities integral to focusing channel
  - Fields ranging from LTS to HTS conductor regime

Muon Ionization 6-Dimensional Cooling Channel



- Characteristics:
  - Emittance exchange channel for TeV-scale colliders (trade increased longitudinal beam emittance for smaller transverse emittance
  - Baseline: 30T class HTS solenoids with a>25mm

Muon Ionization Final Cooling Channel

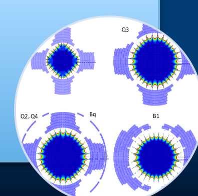


- Characteristics:
  - Present baseline based on the use of Rapid Cycling Synchrotrons
  - Requires magnets capable of ~400Hz operation with >1.5T peak fields

Acceleration to the TeV Energy Scale for Muon Colliders

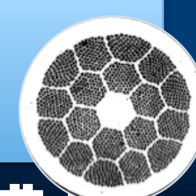
- Characteristics:
  - Decaying muon beams mean that luminosity is inversely proportional to circumference
  - 10T dipole ⇨ 15-20T dipoles improves luminosity
  - Radiation environment
  - Challenging IR magnets

Muon Collider Magnet Needs



- Characteristics:
  - A MC (w/decaying beams) obtains the greatest performance enhancement of any HEP collider from HTS magnet technology
  - High quality HTS cables and magnets must be a priority

HTS Magnet Development



Feasibility R&D through End of Decade